Perspectives on Measurement Systems

1.0 Introduction

Observations of physical, chemical and biological properties of airborne, terrestrial and aquatic systems form the basis for environmental assessments. Measurement systems typically are developed to meet fairly specific objectives along programmatic lines. Examples include tracking trends of acidy and acid neutralizing capacity through the surface water Time/LTM networks, determining compliance with National Ambient Air Quality Standards (NAAQS) in the State and Local Air Monitoring Networks (SLAMs) and establishing visibility baselines and associated progress in the Interagency Monitoring of Protected Visual Environments (IMPROVE) network. Observations serve multiple purposes beyond a programs primary objective there are a number of common threads inherent in most observation systems. These commonalities include characterizing current environmental state, parameterizing physical/chemical processes, tracking change (trends) of environmental conditions, developing causality associations between observations and responses, providing inputs to and evaluation data for models. These common threads enable the data user community to weave together information from disparate networks to service numerous applications, despite recognized spatial, temporal and compositional gaps instrument induced artifacts. Recognizing both synergisms among networks as well as inherent limitations, what is the capacity of the current state of observational systems to address the central themes of accountability, multiple pollutants and multiple media linkages.

In addressing the issue of how well suited our observation programs are in addressing challenges posed by the NAS report, this chapter will provide a broad overview of existing (and planned) observational platforms and campaigns in North America focused primarily on atmospheric measurements and including aquatic and terrestrial (soil and sediment) chemistry measurement programs. Programs addressing biological responses relevant to ecosystem and human health effects are addressed in the health effects and ecosystem chapters. This broad inventorying effort is intended to identify areas of opportunity and information gaps to foster integration across pollutant categories, environmental media and throughout the source to effects indicators continuum. The following questions are considered throughout this chapter:

1. What observations are in place (or planned) to support multiple pollutant – multiple media air quality management practice in North America? What else is recommended?
2. What observation systems and needs facilitate linkages across the following indicator categories:
    a. Source emissions – ambient air
    b. Ambient air – human exposure inhalation
    c. Ambient air – deposition to aquatic and terrestrial systems
    d. Deposition – aquatic and terrestrial chemistry

2.0 Summary Of Existing Observation Systems

This chapter provides an inventory of current environmental observations systems focused mostly on routine ambient air quality networks, with limited information on surface water and soil chemistry networks.

2.1 Atmospheric systems.

Observational systems supporting air quality and related assessments include routine regulatory networks, deposition networks, intensive field studies, remote sensing systems, sondes, aircraft campaigns, satellites, and focused fixed site special purpose networks. Major networks currently operating are emphasized; reference to other networks that have been discontinued, or that were only intended for a specific operating period, is also provided. The focus is on routinely operating North American air quality networks, with limited coverage of European and international efforts relevant to North American assessments.

The scope of network coverage is broad and relatively shallow, reflecting intent to describe the observational foundation enabling integration of spatial scales, environmental media and pollutant categories. In addition to fixed-site, surface-based air quality networks, systems providing total Earth column and vertical gradient information meteorological programs are included as well as operations designed to address climate forcing gases and aerosols, long range transport and stratospheric ozone. Cursory descriptions of recent intensive field campaigns are included to further foster integration of multiple observation platforms and air quality modeling platforms.

The information generally is organized by measurement category covering a range of networks and programs:

Section 2.1.1: Major Routine United States and Canadian Operating Air Monitoring Networks
Section 2.1.2: Intensive Field Campaigns
Section 2.1.3: Air Monitoring Networks for Climate Forcing, Transport, and Stratospheric Ozone
Section 2.1.4: Observation Systems Providing Vertical Profile Information
Section 2.1.5: National Routine Meteorological Monitoring Networks
Section 2.1.6: Satellite–Based Air Quality Observing Systems
Section 2.1.7: Surface water and soil/sediment measurement programs

Section 2.1.8: European Air Monitoring Networks
Section 2.1.9: Monitoring Networks for Persistent Organic Pollutants (POPs)

Summary information covering contacts, site numbers, operational period, and measurement parameters are tabulated in Appendix A.

2.1.1 Major Routine North American Operating Air Monitoring Networks

Routine ambient air and deposition monitoring networks in North America provide over 3000 fixed platforms measuring numerous gaseous species and aerosol properties (Table 1, Figure 1). Many of these longstanding U.S. network systems were catalyzed by the 1970 Clean Air Act (CAA), subsequent CAA amendments, NAAQS reviews and National Academy of Sciences (NAS) recommendations resulting in periodic step enhancements in routine networks. Examples include the Clean Air Status and Trends Network (CASTNET) and National Atmospheric Deposition Program (NADP) addressing acidification; the Photochemical

Assessment Measurement Stations in response to persistent ozone pollution, and the PM2.5 monitoring networks following promulgation of the 1997 NAAQS (see text box on evolution of U.S. networks).

In the United States the lead federal agency for integrating the monitoring programs, systems and data management from these networks is frequently EPA. But other agencies, such as NPS, NOAA, DOE, have the lead responsibility for some networks, or are otherwise involved in operation of air monitoring networks. Alternately, some networks are privately operated by interested industry or research groups. In many cases, individual monitoring sites are operated and maintained, and the data are collected, quality assured, reported and analyzed, by local/State/tribal governments, research entities, paid contractors, or private parties. It is especially noteworthy that many of the networks listed are not mutually exclusive and may serve dual purposes or may function as subcomponents of other larger networks.

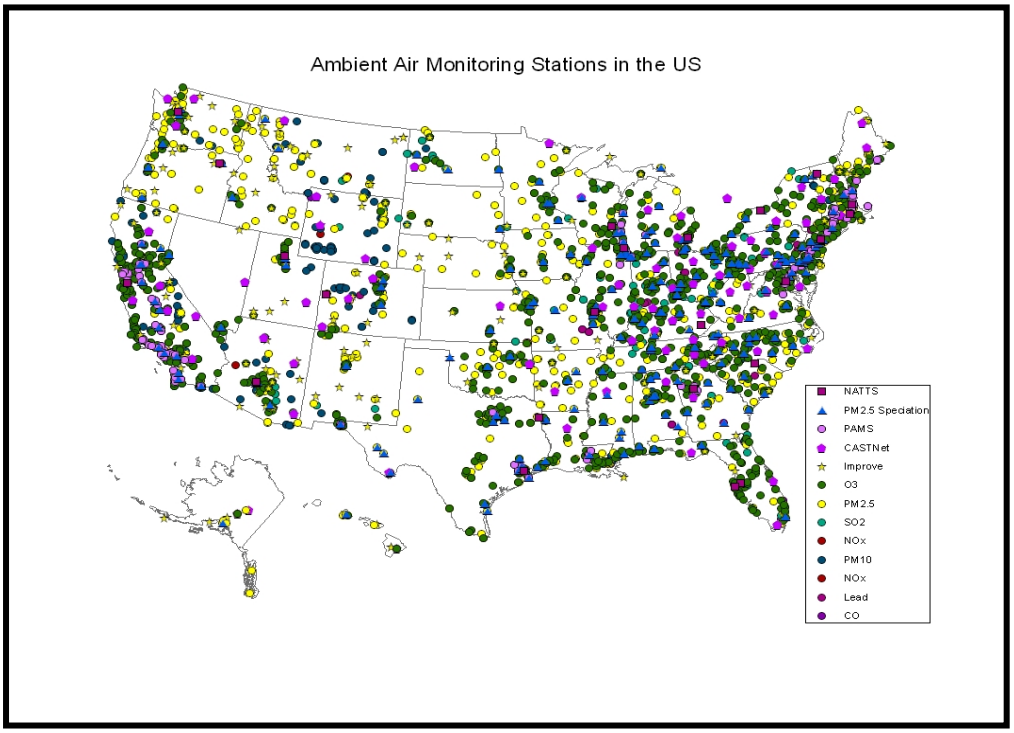

Figure 1. Aggregate map of the majority routine U.S. monitoring stations illustrating relatively broad coverage across the continental U.S. with noted spatial gaps in low populated ares.

TABLE 1. MAJOR ROUTINE OPERATING AIR MONITORING NETWORKS[5]

Network	Lead Federal Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
State / Local / Federal Networks					
NCore[1] -- National Core Monitoring Network	EPA	75	2008	O3, NO/NO2/NOy, SO2, CO, PM2.5/PM10-2.5[2], PM2.5 speciation, NH3, HNO3, Surface Meteorology[3]	http://www.epa.gov/ttn/amtic/monstratdoc.html
SLAMS[1] – State and Local Ambient Monitoring Stations	EPA	~3000	1978	O3, NOx/NO2, SO2, PM2.5/PM10, CO, Pb	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
STN—PM2.5 Speciation Trends Network	EPA	300	1999	PM2.5, PM2.5 speciation, Major Ions, Metals	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
PAMS—Photochemical Assessment Monitoring Network	EPA	75	1994	O3, NOx/NOy, CO, Speciated VOCs, Carbonyls, Surface Meteorology & Upper Air	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
IMPROVE—Interagency Monitoring of Protected Visual Environments	NPS	110 plus 67 protocol sites	1988	PM2.5/PM10, Major Ions, Metals, Light Extinction, Scattering Coefficient	http://vista.cira.colostate.edu/IMPROVE/
CASTNet – Clean Air Status and Trends Network	EPA	80+	1987	O3, SO2, Major Ions, Calculated Dry Deposition, Wet Deposition, Total Deposition for Sulfur/Nitrogen, Surface Meteorology	http://www.epa.gov/castnet/
GPMP—Gaseous Pollutant Monitoring Network	NPS	33	1987	O3, NOx/NO/NO2, SO2, CO, Surface Meteorology, (plus enhanced monitoring of CO, NO, NOx, NOy, and SO2 plus canister samples for VOC at three sites)	http://www2.nature.nps.gov/air/Monitoring/network.cfm#data
POMS—Portable Ozone Monitoring Stations	NPS	14	2002	O3, surface meteorology, with CASTNet-protocol filter pack (optional) sulfate, nitrate, ammonium, nitric acid, sulfur dioxide	http://www2.nature.nps.gov/air/studies/portO3.cfm
Passive Ozone Sampler Monitoring Program	NPS	43	1995	O3 dose (weekly)	http://www2.nature.nps.gov/air/Studies/Passives.cfm
NADP/NTN—National Atmospheric Deposition Program / National Trends Network	USGS	200+	1978	Major Ions from precipitation chemistry	http://nadp.sws.uiuc.edu/
NADP/MDN—National Atmospheric Deposition Program / Mercury Deposition Network	None	90+	1996	Mercury from precipitation chemistry	http://nadp.sws.uiuc.edu/mdn/
AIRMoN—National Atmospheric Deposition Program / Atmospheric Integrated Research Monitoring Network	NOAA	8	1984	Major Ions from precipitation chemistry	http://nadp.sws.uiuc.edu/AIRMoN/
IADN—Integrated Atmospheric Deposition Network	EPA	20	1990	PAHs, PCBs, and organochlorine compounds are measured in air and precipitation samples	http://www.epa.gov/glnpo/monitoring/air/
NAPS—National Air Pollution Surveillance Network	Canada	152+	1969	SO2, CO, O3, NO, NO2, NOx, VOCs, SVOCs, PM10, PM2.5, TSP, metals	http://www.etcentre.org/NAPS/
CAPMoN—Canadian Air and Precipitation Monitoring Network	Canada	29	2002	O3, NO, NO_2, NO_y, PAN, NH_3, $PM_{2.5}$, PM_{10} and coarse fraction mass, PM2.5 speciation, major ions for particles and trace gases, precipitation chemistry for major ions	http://www.msc.ec.gc.ca/capmon/index_e.cfm
Mexican Metropolitan Air Quality Network	Mexico	93	???	O3, NOx, CO, SO2, PM10, TSP	See CEC, 1997[7]

TABLE 1. MAJOR ROUTINE OPERATING AIR MONITORING NETWORKS (continued)					
Air Toxics Monitoring Networks					
NATTS—National Air Toxics Trends Stations	EPA	23	2005	VOCs, Carbonyls, PM10 metals[4], Hg	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
State/Local Air Toxics Monitoring	EPA	250+	1987	VOCs, Carbonyls, PM10 metals[4], Hg	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
NDAMN—National Dioxin Air Monitoring Network	EPA	34	1998 - 2005	CDDs, CDFs, dioxin-like PCBs	http://cfpub2.epa.gov/ncea/cfm/recordisplay.cfm?deid=22423
Tribal Monitoring Networks					
Tribal Monitoring[6]	EPA	120+	1995	O3, NOx/NO2, SO2, PM2.5/PM10, CO, Pb	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
Industry / Research Networks					
New Source Permit Monitoring	None	variable	variable	O3, NOx/NO2, SO2, PM2.5/PM10, CO, Pb	Contact specific industrial facilities
HRM Network—Houston Regional Monitoring Network	None	9	1980	O3, NOx, PM2.5/PM10, CO, SO2, Pb, VOCs, Surface Meteorology	http://hrm.radian.com/houston/how/index.htm
ARIES / SEARCH—Aerosol Research Inhalation Epidemiology Study / SouthEastern Aerosol Research and Characterization Study experiment	None	8	1992	O3, NO/NO2/NOy, SO2, CO, PM2.5/PM10, PM2.5 speciation, Major Ions, NH3, HNO3, scattering coefficient, Surface Meteorology	http://www.atmospheric-research.com/studies/SEARCH/index.html
SOS - SERON—Southern Oxidant Study - Southeastern Regional Oxidant Networks	EPA	~40	1990	O3, NO, NOy, VOCs, CO, Surface Meteorology	http://www.ncsu.edu/sos/pubs/sos3/State_of_SOS_3.pdf
National/Global Radiation Networks					
RadNet—formerly Environmental Radiation Ambient Monitoring System (ERAMS)	EPA	200+	1973	Radionuclides and radiation	http://www.epa.gov/enviro/html/erams/
SASP -- Surface Air Sampling Program	DHS	41	1963	^{89}Sr, ^{90}Sr, naturally occurring radionuclides, ^{7}Be, ^{210}Pb	http://www.eml.doe.gov/databases/sasp/
NEWNET—Neighborhood Environmental Watch Network	DOE	26	1993	Ionizing gamma radiation, Surface Meteorology	http://newnet.lanl.gov/stations.asp
CTBT—Comprehensive Nuclear Test Ban Treaty	DOE	80	1996	Radionuclides and noble gases	http://www.clw.org/archive/coalition/briefv3n14.htm
Other Networks					
UV Index—EPA Sunwise Program	EPA	~50 U.S. cities	2002	Calculated UV radiation index	http://www.epa.gov/sunwise/uvindex.html
UV Net—Ultraviolet Monitoring Program	EPA	21	2002	Ultraviolet solar radiation (UV-B and UV-A bands)	http://www.epa.gov/uvnet/access.html
UV-B Monitoring and Research Program	USDA	35	1992	Ultraviolet-B radiation	http://uvb.nrel.colostate.edu/UVB/jsp/uvb_climate_network.jsp
SURFRAD—Surface Radiation Budget Network	NOAA	7	1993	solar and infrared radiation, direct and diffuse solar radiation, photosynthetically active radiation, UVB, spectral solar, and meteorological parameters	http://www.srrb.noaa.gov/surfrad/index.html
PRIMENet – Park Research & Intensive Monitoring of Ecosystems NETwork	NPS	14	1997	ozone, wet and dry deposition, visibility, surface meteorology, and ultraviolet radiation	http://www.forestry.umt.edu/research/MFCES/programs/primenet/
BioWatch	No details				

Footnotes:

Footnotes:

1. NCore is a network proposed to replace NAMS, as a component of SLAMS; NAMS are currently designated as national trends sites.
2. PM10-2.5 -- proposed new NAAQS.

3. Surface Meteorology includes wind direction and speed, temperature, precipitation, relative humidity, solar radiation (PAMS only).
4. PM10 metals may include arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, and others.
5. Some networks listed separately may also serve as subcomponents of other larger listed networks; as a result, some double counting of the number of individual monitors is likely.
6. The number of sites indicated for tribal monitoring is actually the number of monitors, rather than sites. The number of sites with multiple monitors is probably less than 80.
7. CEC, 1997. Background Document on Air Quality Data Compatibility. Prepared for the North American Monitoring and Modeling Project of the CEC, August 1997

Summaries of routine network operations by pollutant category

Inorganic gases.

The majority of U.S. sites measuring criteria gases (ozone, nitrogen oxides, sulfur dioxide and carbon monoxide) are incorporated within the SLAMS networks. Most of the SLAMS sites are located in populated urban locations with a variety of siting requirements typically intended to site for high concentration locations resulting in an emphasis on downwind (from urban center) locations for ozone, center city locations for nitrogen oxides, roadway intersection and canyon type locations for CO and proximity to major power generating facilities for SO_2. Derived estimates of nitrogen oxides based on standard chemiluminescence techniques continue to include additional reactive nitrogen (e.g, nitric acid and peroxy acetyl nitrate) leading to positive biases in the total NOx reported during periods not dominated by fresh emissions. Most monitoring platforms include multiple sensors to improve efficiency of network operations and adding interpretive value. Ozone and $PM_{2.5}$ remain our most significant criteria pollutants relative to NAAQS exceedances, with greater than 1000 ozone sites in operation. Ozone monitoring in rural and regional representative locations under CASTNET, NPS and USFS and SEARCH network in the Southeastern U.S. compliment the SLAMS urban oriented networks. CASTNET sulfur dioxide measurements are widely used for model evaluation purposes as the sites are located in rural areas far removed from concentrated plume impacts of single emissions sources. The CASTNET filter pack systems provide weekly integrated values; and most compliance oriented instruments operate continuously reporting hourly averaged values.

Reactive nitrogen, Nitric acid and ammonia

Total reactive nitrogen (NOy), nitric acid and ammonia serve a variety needs related to emission inventory and model evaluation, inputs into observational based models which characterize the responsiveness of a secondarily formed pollutant (e.g., ozone or ammonium nitrate) to specific precursor reductions (VOC, NOx, or ammonia) and, with particle nitrate, are important components of the atmospheric nitrogen budget supporting downstream watershed and accountability assessments. These nitrogen species, in addition to true NO_2 (and particulate ammonium), are components of the total nitrogen budget and remain poorly categorized. A scarcity of reliable, cost effective measurement methods instrumentation combined with minimal regulatory incentive curtail advancements in nitrogen measurements. In the United States, the SEARCH network is the only source of routine ambient air measurements of NOy, ammonia and nitric acid. Canada in partnership with CASTNET recently has deployed a network of inexpensive passive ammonia samplers which have promise for characterizing broad spatial patterns, with extended averaging times beyond 24 hours. Most ammonia sampling is focused on high source regions in agricultural settings designed to improve emission factors for ammonia, resulting in very limited ammonia characterization of ambient environments. The 75 NCore level 2 sites are exploring denuder methods to collect 24 hour integrated ammonia samples consistent with sample collection periods in the speciation network. Reliable and cost effective routine semi-continuous methods for nitric acid and ammonia currently bare not available.

Mercury

Gaseous and particle bound mercury are not routinely measured, with the exception of SEARCH and a few research sites. Simultaneous measurement of speciated mercury; elemental Hg^0, reactive Hg^{+2}, and particulate bound Hg is desired to evaluate transformation and deposition patterns of emitted elemental mercury which deposits mostly as reactive gaseous mercury. Dry ambient measurements would complement the existing precipitation based Mercury Deposition Network (MDN) which includes over 85 sites in the United State. Speciated dry mercury measurements are considered expensive and relatively complex. An iniatitive catalyzed by through EPA's Office of Atmospheric Programs (OAP) is establishing a modest number of speciated dry Hg sites as part of the NADP (Figure.??.), with the expectation that using centralized operations and laboratory in the NADP structure will maintain consistency across those stations participating through NADP.

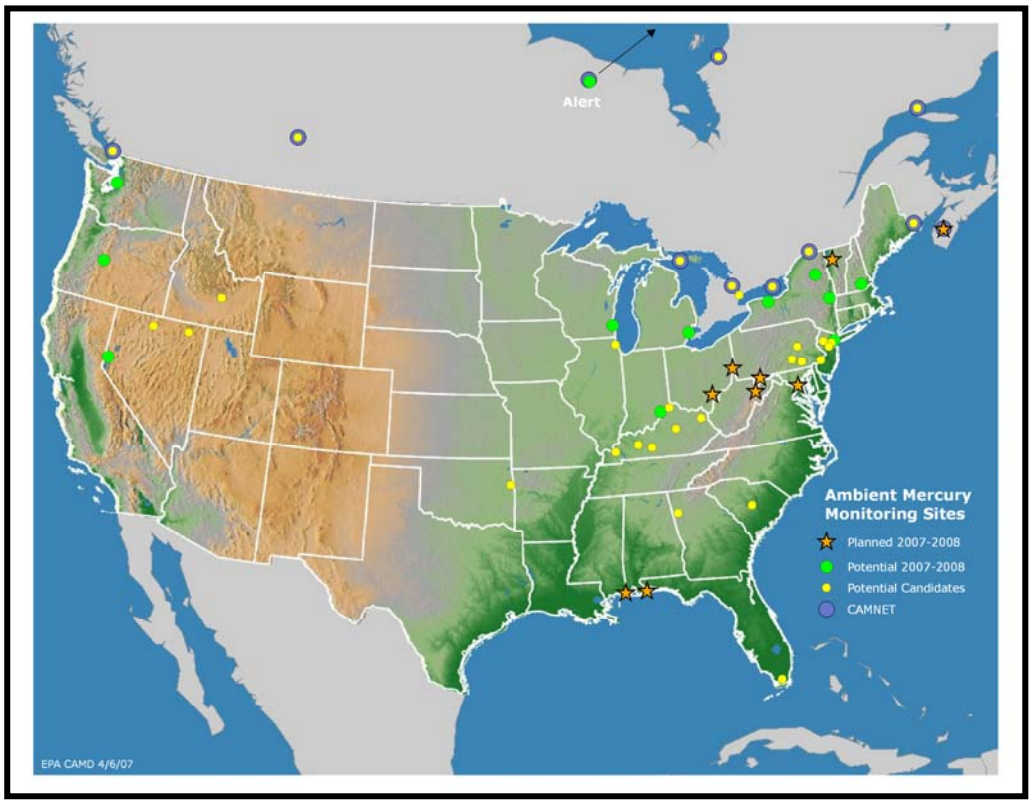

Figure 2. Current and proposed dry mercury measurement sites (source, D. Schmeltz).

Organic gases

Most routine organic gas measurements in the United States are conducted through the Photochemical Assessment Measurement Stations (PAMS) and Air Toxics Measurement programs (figure 3). PAMS measurements at over 60 locations include a suite of 55 volatile organic compounds (VOCs) dominated by urban based nonpolar, fresh emissions species (alkanes, alkenes and aromatics) and two carbonyls (formaldehyde and acetaldehyde). A combination of continuously operating on site gas chromatographs and bulk sampling canisters and cartridges (with subsequent laboratory analysis) result in a broad mix of temporally resolved data which operates throughout the ozone season (generally May through September) with some exceptions. The U.S. air toxics measurement programs include 22 National Air Toxics Trends Sites (NATTS) and several stations operated by State and local agencies. The NATTS started operations in 2002 and currently require sampling and analysis for over twenty gaseous and aerosol species (Table 1).

The Urban Air Toxics Monitoring Program (UATMP) is a contractor service laboratory that State and local agencies access for laboratory analysis of canisters, cartridges and filters for a variety of VOCs, Semivolatile organic compounds (SVOCs) and metals considered HAPs. UATMP sampling schedule generally is year round (virtually all HAPs assessments involve cancer risk assessments based on chronic exposures) with a collection frequency of every 6^{th} or 12^{th} day. In addition to non-polar VOCs, the UATMP includes a varied suite of halogenated organics, polar organics, carbonyls and SVOCs.

The PAMS program was developed partly in response to the National Academy of Science 1991 Report, Rethinking the Ozone Problem in Urban and Regional Air Pollution (NAS, 1991). The program was somewhat revolutionary as it provided significant resources to measure precursor gases with the intent of better characterizing trends in precursor gases and supporting development of emission control strategies. Historically, most highly funded measurement campaigns focused on criteria pollutant measurements. Unfortunately, the PAMS program lacked adequate infrastructure support for: technology transfer of new methods, sustained quality assurance, data analysis protocols and execution. These gaps combined with difficulties in communicating complexities of nonlinear systems continues to compromise the overall value of PAMS. Clearly, a design effort should be conducted addressing needs for VOC measurements across North America taking into account science developed over the last two decades and emerging assessment needs.

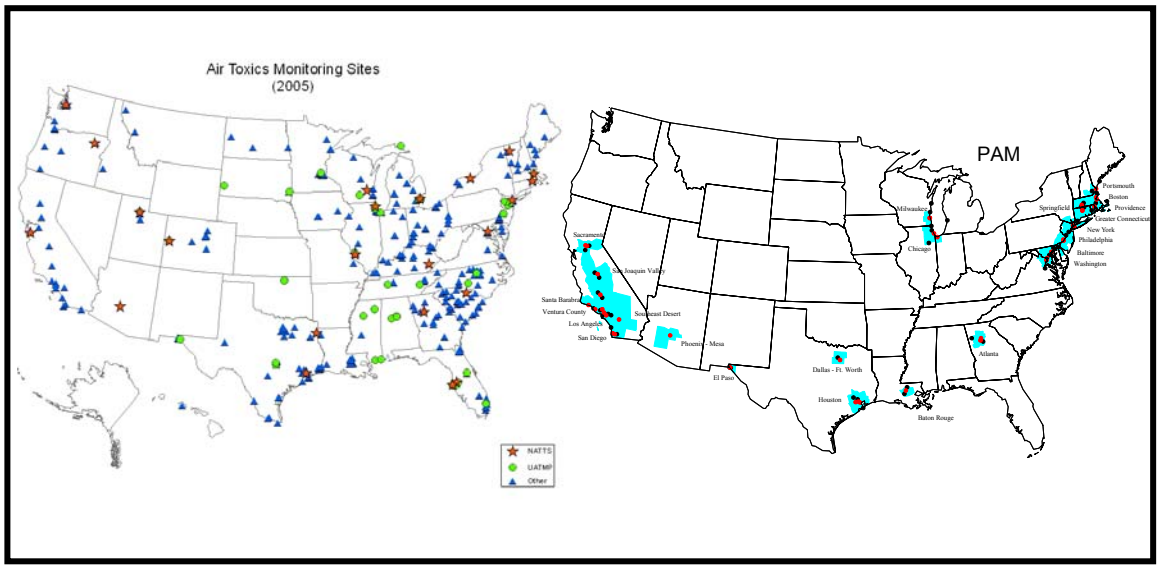

Figure 3. Location of PAMS and air toxic monitoring sites reflecting the majority of routine U.S. VOC measurement locations**.**

Semivolatile organic compounds (SVOC) and perisistent organic compounds (POPs).

A variety polcyclic aromatic hydrocarbons (PAH – e.g., Napthalene and benzo(a) pyrene) and organochlorines (PCBs, pesticides and dioxins) generally have low volatility and can exist in gaseous or particle phases with relatively long atmospheric life times. The terms SVOC and POP sometimes are used interchangeably and in certain conventions include specific named compounds. Because of their stability and semivolatile behvior, many SVOCs are conveyed along long distance transport corridors and often are re-entrained into the atmosphere after deposition (this cycling often is referred to as grasshopper effect) and impart associated effects in areas far removed (e.g., Arctic) from source regions.

The integrated Atmospheric Deposition Program (IADN – discussed below with precipitation networks) initiated in 1990 analyzes PAHs, PCBs, and organochlorine compounds in air and precipitation samples in the Great Lakes Region of the U.S. and Canada. Approximately 20 PAH compounds are analyzed as part of the UATMP program. A pilot program is underway in the NATTS that potentially could evolve to requiring the addition Napthalene and benzo(a) pyrene to the NATTS list.

EPA established a 30 site rural National Dioxin Air Monitoring Network (NDAMN) in the late 1990's that performed long term average (28 days) sampling for dioxins and PCBs during each season (Cleverly et al., 2004). Network operations ended in 2005.

The majority of SVOC measurement programs are organized through international bodies associated with the United Nations and often based in Europe (Table 2).

TABLE 2. MONITORING NETWORKS FOR PERSISTENT ORGANIC POLLUTANTS (POPs)

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Global Monitoring of Persistent Organic Pollutants (POPs)[1]	UNEP – United Nations Environment Programme	N/A	2003	Activities include developing guidance on sampling and analysis of POPs, QA/QC procedures, data treatment and communication and data assessment. In addition the programme will include an electronic discussion group on POPs monitoring issues where existing programs and laboratories are invited to participate and share their experience on this subject.	http://www.chem.unep.ch/gmn/default.htm
AMAP – Artic Monitroing and Assessment Programme	NOAA (as U.S. representative to the 8 nation Artic Council)	???	~1991	Air/aerosol sampling for POPs, heavy metals, radioactivity and acidification parameters; bulk precipitation and snowpack sampling to estimate deposition[2]	http://www.amap.no/
EMEP -- Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe	UNECE – United Nations Economic Commission for Europe	17	1991	Benzo(a)pyrene, PCBs, hexachlorobenzene, Chlordane, lindane, hexachlorocyclohexane, DDT/DDE in precipitation and gas particles	http://www.chem.unep.ch/gmn/012_emep.htm
GAPS – Global Atmospheric Passive Sampling	UNEP – United Nations Envrionment Programme	50	2004	12 chemicals including Aldrin, Chlordane, DDT, Deldrin, Endrin, Heptachlor, Hexachlorobenzene, Mirex, PCBs, Dioxins(PCDDs), Furans(PCDFs), Toxaphene and other pollutants	http://pubs.acs.org/cgi-bin/article.cgi/esthag/2004/38/i17/html/es040302r.html
NDAMN – National Dioxin Air Monitoring Network	EPA	34	1998 - 2005	CDDs. CDFs, dioxin-like PCBs	http://cfpub2.epa.gov/ncea/cfm/recordisplay.cfm?deid=22423
IADN -- Integrated Atmospheric Deposition Network	EPA	20	1990	PAHs, PCBs, and organochlorine compounds are measured in air and precipitation samples	http://www.epa.gov/glnpo/monitoring/air/
EMAP – Environmental Monitoring and Assessment Program	EPA	12,600	1988	Oriented to ecological and water monitoring	http://www.epa.gov/emap/index.html

Footnotes:

1. The 12 POPs targeted by the United Nations sponsored Stockholm Convention (December 2000) are Aldrin, Chlordane, Dieldrin, DDT, Endrin, Heptachlor, Mirex, Toxaphene, Polychlorinated Biphenyls (PCBs), Hexachlorobenzene (HCB), Dioxins, and Furans.
2. For AMAP the following pollutants are monitored:
-- POPs include such pollutant families as Chlorobenzenes, Hexachlorocyclohexanes, Clordanes, Heptachlor, DDT, Mirex, Toxaphene, Dieldrin/endrin, PCDD/PCDF, Non-ortho PCBs (coplanars), PCB congeners, Current use pesticides, Polycholrinated naphthalenes, Short chain chlorinated paraffins (CP), other POPs, PAHs and petroleum hydrocarbons.
-- Heavy metals include Cd, Cu, Hg, Pb, Zn, Cr, Ni, As, Se, Al, Fe, and V.
-- Radiactivity includes Gamma spectroscopy, ^{131}I, ^{137}Cs, ^{134}Cs, ^{90}Sr, ^{210}Po, ^{99}Tc, and $^{239,240}PU$.
-- Acidification parameters include SO2, NOx, NH3, pH, SO4, NO3, NH4, DOC, Mg, Ca, K, Na, AL, Cl, Conductivity, N_{tot}, P_{tot}, and Particulates.

Particulate Matter mass

Nearly 1500 $PM_{2.5}$ gravimetric sites were established by 2000 to determine nonattainment status of counties throughout the United States, following the 1997 promulgation of the $PM_{2.5}$ particulate matter standard. The network has evolved to add over 500 continuous $PM_{2.5}$ monitors, and a reduction of 24 hour gravimetric samplers below 1000 sites (Figure 4), that support air quality forecasting and public notification of adverse air quality through AIRNOW using the Air Quality Index (AQI), a generalized indicator of exposure concern linked to the NAAQS (http://www.epa.gov/airnow/). While this expansion of continuous $PM_{2.5}$ sites adds spatial coverage of highly temporally resolved information, the mix of instrument types compromises data harmonization across sites and geographic areas with different operational characteristics. In recognition of potential geographic differences, EPA has developed monitoring policy (EPA, 2006a) for regionally approved methods (RAM) that would lead to equivalency status for continuous $PM_{2.5}$ samplers and compliance applications relative to the NAAQS. Nevertheless, there will remain issues regarding data harmonization across site locations as well as the use of the gravimetric mass measurement as an adequate indictor of "true" aerosols when in theory, in–situ continuous instruments have the potential to yield data less impacted by measurement artifacts associated with volatility losses, gas adsorption and related issues associated with filter handling and equilibration. It should be noted that all filter based speciation sites (see below) also provide a gravimetric $PM_{2.5}$ mass value relatively consistent with the standard equivalent methods used for compliance.

There remain over 1000 PM_{10} mass monitors in the United States, despite concerns regarding interpretability of data given the inclusion of the $PM_{2.5}$ size fraction as well as requests from the health effects communities to provide separation of the coarse ($PM_{10-2.5}$) fraction. A modest network of 75 $PM_{10-2.5}$ mass instruments will be included in the NCore network.

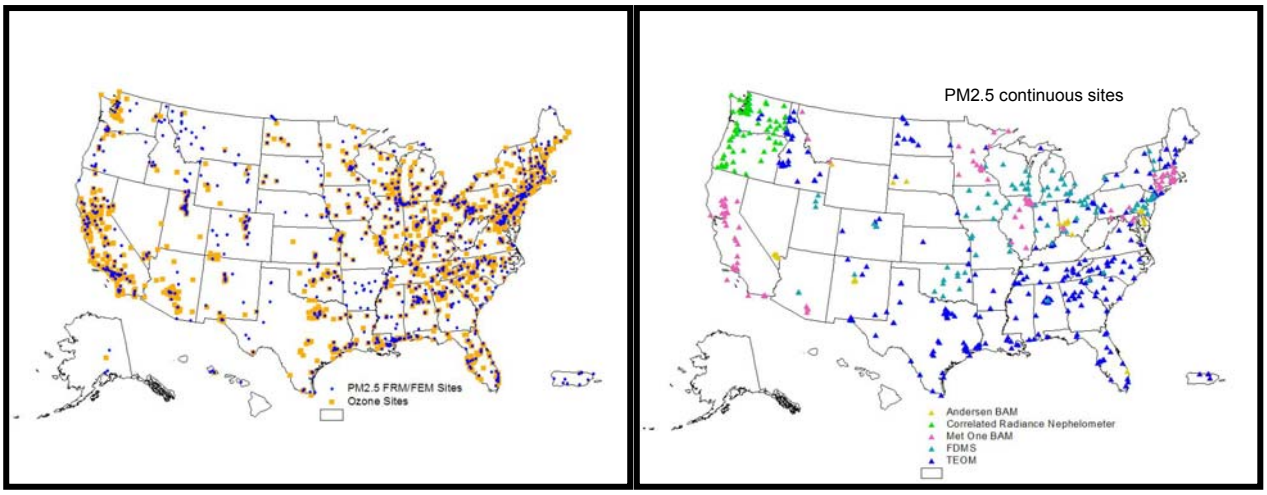

Figure 4. Maps illustrating breadth of PM2.5 FRM/FEM and ozone network (left) and PM2.5 continuous samplers (right). These combined networks represent the dominant use of of U.S. air quality observations for NAAQS attainment designations and air quality forecast reporting.

Particulate matter speciation

The IMPROVE network has provided nearly a two decade record of major components (sulfate, nitrate, organic and elemental carbon fractions, and trace metals) of $PM_{2.5}$ aerosols in pristine areas of the United States. Over 300 speciation sites were added from 2000 - 2002 in urban areas of the United States to assist assessment efforts related to the $PM_{2.5}$ standard. This coverage (figure 5) across urban and rural areas has been a widely used resource across disciplines (exposure/epidemiological, atmospheric science communities), organizations (academia, industry, government agencies) and several spatial scales of interest (long range hemispheric transport to near source). The speciation networks typically collect a 24 hour sample every three, and sometimes six, days. [Jeff, please discuss Canada, I recall at least one site with daily speciation]. CASTNET provides weekly averaged measurements of major ions (SO4, NO3, CA, Na, K, NH4, Mg) integrated over all aerosol sizes through open face filter packs. Daily, 24 hour speciation collection often requested by health effects researchers is limited to less than five sites in Canadian and U.S. (SEARCH) networks. Similarly only a handful of sites provide near continuous speciation data, usually limited to some combination of sulfate, carbon (organic and elemental splits) and nitrate; enabling insight into diurnal patterns for diagnosing various cause-effect phenomena related to emissions characterization, source attribution analysis and model evaluation. The 22 NATTS include aetholometers measuring semi-continuous light absorption, often used as a surrogate for elemental carbon.

The PM supersites program (Solomon et al., 2007) provided highly resolved aerosol measurements at eight U.S. cities for a mix of time periods from 1999 through 2004. Depending on location and time period, a number instrument configurations were deployed ranging from additional spatial coverage of standard speciation sites to systems capturing near continuous size distributed chemical composition profiles.

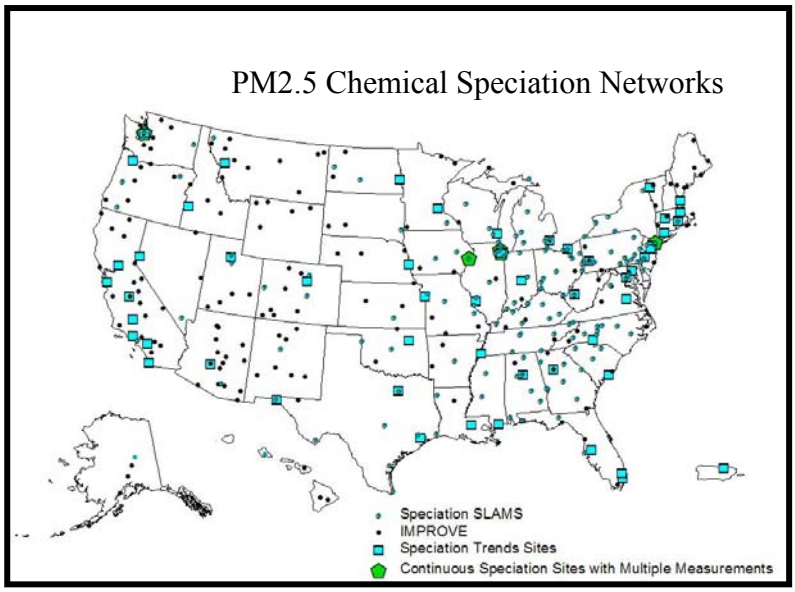

Figure 5. Locations of chemical speciation sites delineated by program type.

Metals

Chemical speciation networks provide scans of trace metals through X ray fluorescence (XRF). Limited to the $PM_{2.5}$ size cut, those data typically are used as indicators grouped with other metals to support source attribution analyses. The majority of metals data are collected through air toxics measurement programs which typically collect total suspended particles (TSP) or a PM_{10} fraction for subsequent metals analysis using Inductively coupled Plasma (ICP) mass spectrometry (MS). Emphasis is placed on high risk related metals such as arsenic, cadmium, chrome, and lead; although data on a variety of other metals often is reported. Hexavalent Chromium is required as part of the NATTS and is collected on coated filters and analyzed via Ion Chromatography. The IADN program analyses for selected metals (As, Pb, Cd, Se).

Precipitation based networks

Precipitation chemistry is the primary link between atmospheric and terrestrial and aquatic systems. The National Atmospheric Deposition Program (NADP, http://nadp.sws.uiuc.edu/) oversees a network of over 250 sites (figure 6) that analyze for most major ions key to aquatic chemistry characterization utilized in most watershed models addressing acidification and eutrophication effects. The NADP includes the Mercury Deposition Network (MDN, over 90 sites) and a seven site Atmospheric Integrated Research Monitoring Network (AIRMoN) providing greater temporal resolution.

The joint Canadian-U.S. Integrated Atmospheric Deposition Network (IADN, http://www.msc-smc.ec.gc.ca/iadn/index_e.html) includes a mix of master and satellite stations across the Great Lakes that sample both precipitation and ambient air for a range of toxics compounds. IADN emphasizes many of the more persistent organic compounds including PCB, pesticides and dioxins and toxics metals (lead, cadmium, arsenic and selenium).

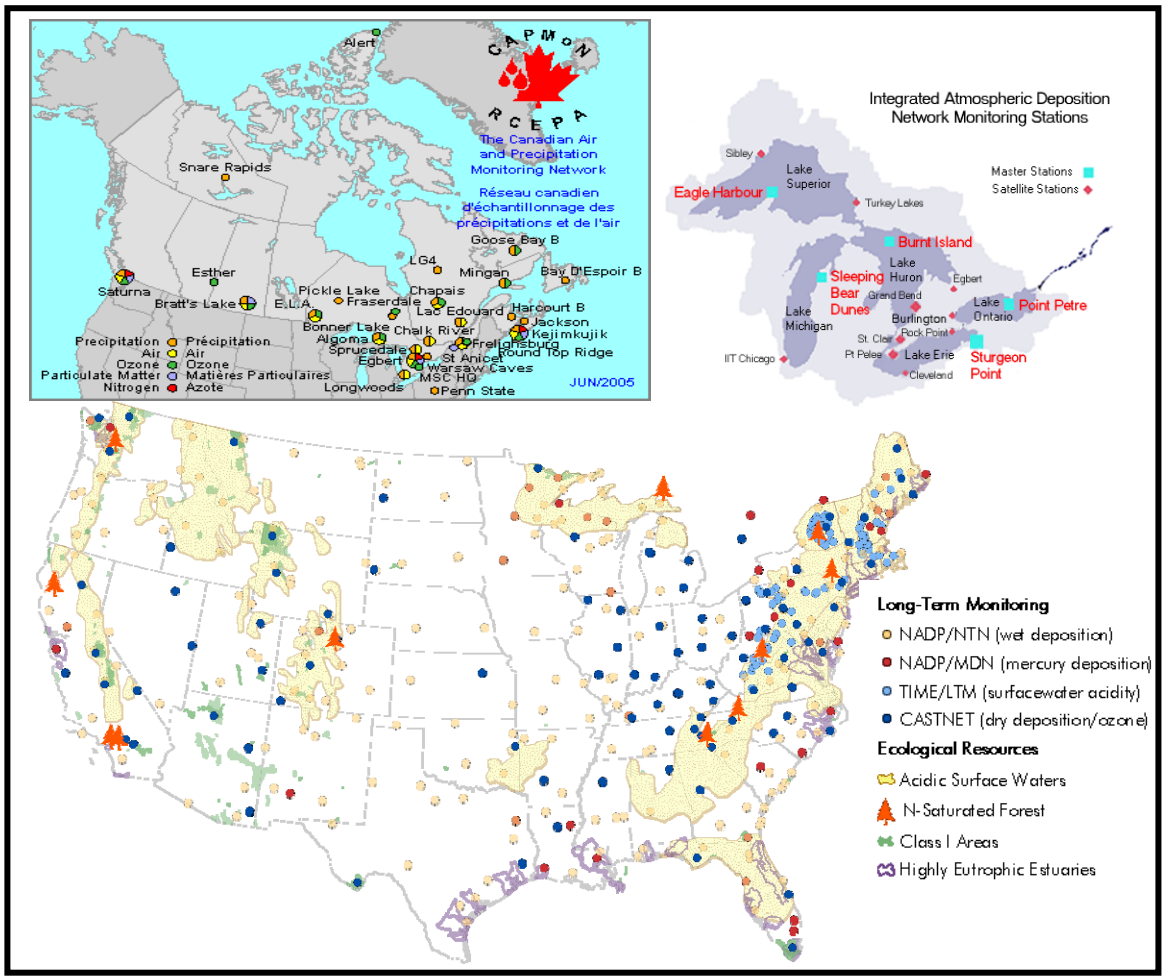

Figure 6. Routinely operating North American precipitation and surface water networks: Upper left, Canadian Air and Precipitation Monitoring Network (CAPMON); Upper left, Integrated Atmospheric Monitoring Deposition Network (IADN); Bottom, National Atmospheric Deposition Monitoring Program (NADP) with Time/LTM surface chemistry sites.

Evolution of United States Air Monitoring Networks. *The 1970 Clean Air Act (CAA) established a framework for the original National Ambient Air Quality Standards (NAAQS) and drove the design and implementation of the NAMS and SLAMS networks in the late 1970s. These networks were intended primarily to establish non-attainment areas with respect to the NAAQS which include ozone, sulfur dioxide, nitrogen dioxide, carbon dioxide, lead and particulate matter (PM). The NAMS/SLAMS networks have evolved over time (Figure 7) as a result of cyclical NAAQS review and promulgation efforts leading to changes in measurement requirements related to averaging times, locations and the various size cuts associated with PM.*

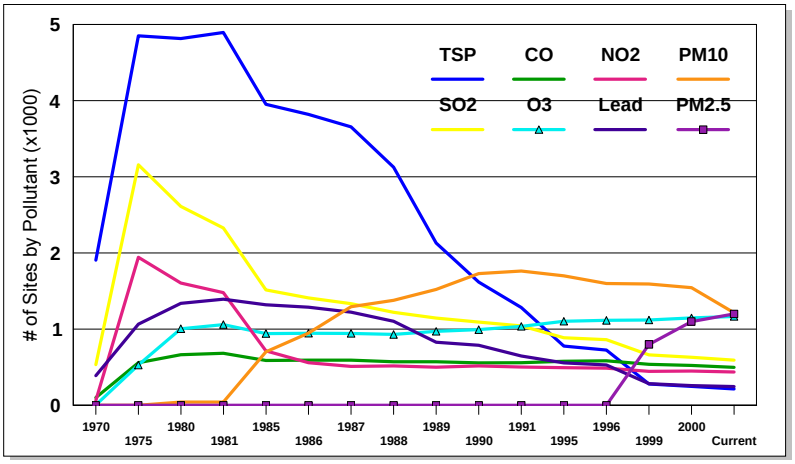

Figure 7. Evolution of U.S. air network growth.

Relatively wide geographical distribution and persistence of Ozone and $PM_{2.5}$ NAAQS exceedances (Figure 8) have lead to these pollutants dominating the national monitoring landscape.

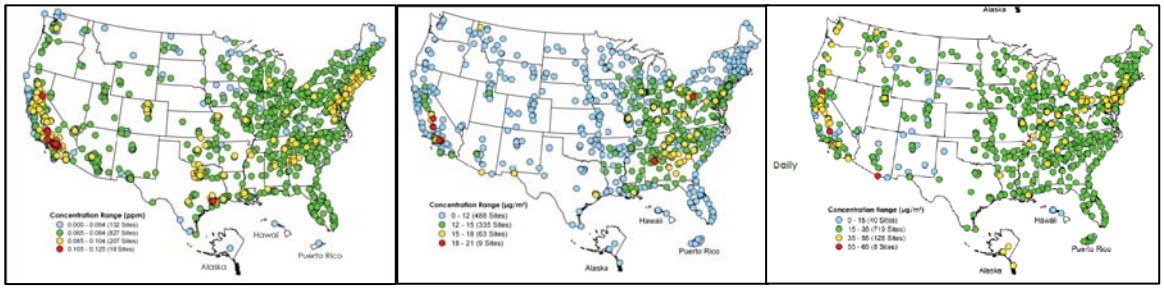

Figure 8. 2006 air quality summaries for ozone, annual average PM2.5 and daily PM2.5. Yellow and red sites indicate values excceeding NAAQS levels (source, EPA).

Two important ambient air networks focused on environmental welfare effects were established in the mid-1980's. The Interagency Agency Monitoring of Protected Visual Environments (IMPROVE) network with over 100 sites in National Parks and other remote locations is used primarily to assess visibility impairment, but has provided a reliable long term record of PM mass and major speciation components and served as a model for the later deployment of EPA's STN network (Figure 5), which has provided an urban complement to characterize aerosol composition (Figure 9).

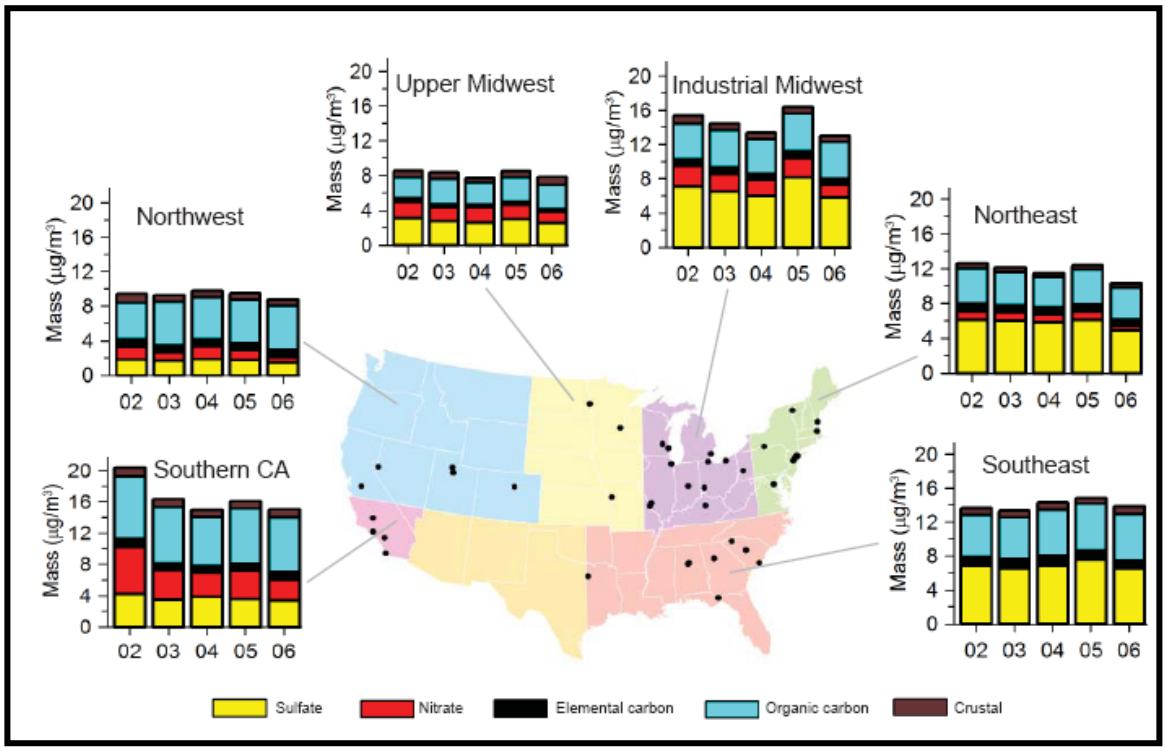

Figure 9. *Regional chemical composition of $PM_{2.5}$ aerosols based on urban speciation sites and averaged over the entire 2006 sampling period (source, 2006 EPA Air Quality Trends Report).*

The Clean Air Status and Trends Network (CASTNET) was established in the early 1990s to track changes in dry deposition of major inorganic ions and gaseous precursors associated with the CAA Title 4 reductions in sulfur and nitrogen, designed to address surface water acidification in Eastern North America. Complementing ongoing precipitation measurements from the National Atmospheric Deposition Program (NADP), CASTNET (Figure 6) has provided a valuable source of model evaluation data for many of the large regional scale applications since the 1990's.

Deployment of the Photochemical Assessment and Measurements Station (PAMS) and the $PM_{2.5}$ networks from the early 1990's through 2002 markedly enhanced the spatial, temporal and compositional attributes of gases and aerosols, partially supporting user needs beyond NAAQS compliance (e.g., public reporting and forecasting of adverse air quality; implementation efforts including air quality model evaluation and source apportionment and pattern (spatial and temporal) analysis of precursor species.

State and local air agencies have measured a variety of metallic and gaseous hazardous air pollutants (HAPs) at over 200 locations since the 1980's. Typically, broad access and use of those data were compromised by a lack of centralized data bases and multiple sampling and laboratory protocols enhancing data uncertainty. In response to this gap in accessible and centralized HAPs observations, a modest 23 site National Air Toxics Trends (NATTS, Figure 3) network was initiated in 2001. Current NATTS species include: Acrolein, Perchloroethylene, Benzene, Carbon tetrachloride, Chloroform, Trichloroethylene, 1,3-butadiene, 1,2-dichloropropane, Dichloromethane, Tetrachloroethylene, Vinyl chloride, Formaldehyde, Acetaldehyde, Nickel compounds,

Arsenic compounds, Cadmium compounds , Manganese compounds,, Beryllium, Lead, Hexavalent chromium, and expected additions of Benzo(a)pyrene, Napthalene.

A new multiple pollutant monitoring network referred to as NCore was incorporated in the 2006 revisions to the particulate matter standards (EPA, 2006). When finally implemented in 2009, NCore will provide a minimum of 75 Level 2 sites (Figure 10) in most major urban areas and important transport corridor and background locations. NCore will include a variety of trace gas, aerosol mass and speciation measurements which are intended to support multiple data user needs (e.g., air quality model evaluation, long term epidemiological studies). In addition to establishing a multiple pollutant measurement framework, the NCore sites are intended to provide a backbone of central location sites that can be complemented by additional (existing and new) stations to address more specific spatial resolution requirements. A lack of funding support has hindered implementation for more intensive Level one sites, intended to promote transition of new technologies into routine networks, which were endorsed by the monitoring subcommittee of the Clean Air Scientific Advisory Committee (CASAC).

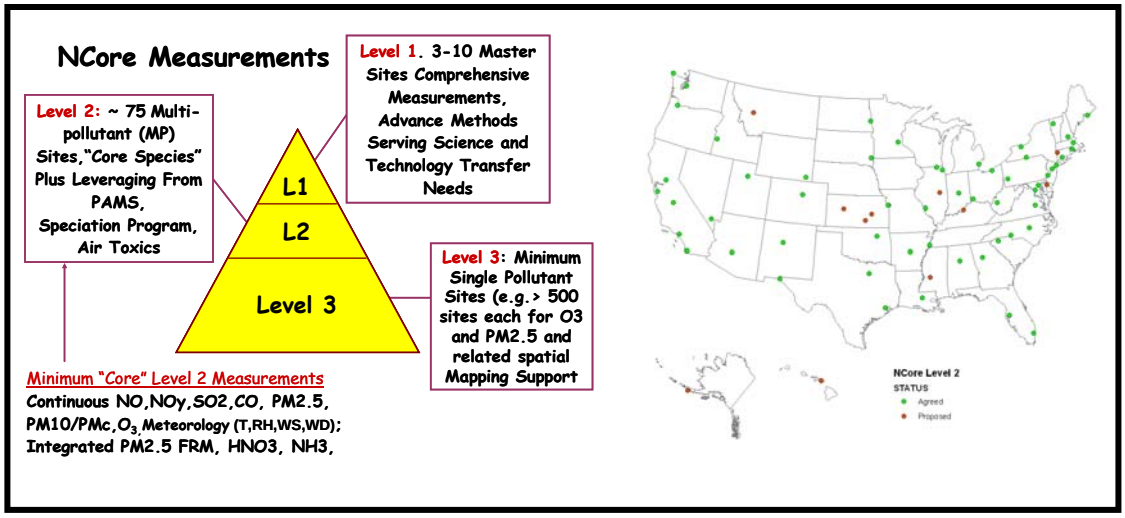

Figure 10. Original 3-tiered NCore design (left) and proposed site locations for Level 2 multiple pollutant sites.

2.1.2 Intensive Field Campaigns

Intensive field campaigns of relatively short duration supplement routine longer term monitoring networks by enhancing spatial, temporal and compositional distribution of atmospheric species to better elucidate physical/chemical processes relevant to the fate, transport and removal of secondarily formed gases and aerosols. Typically, these campaigns utilize some combination of aircraft studies, high time resolved instrumentation and advanced analytical methods (in-situ and laboratory) all complementing routine ground based measurements, which usually do not address reactive gaseous species, aerosol size distributions, organic chemistry characterization and vertically stratified data.

There has been a long history of intensive field campaigns starting with the Regional Air Pollution Study (RAPS) in the 1970's which formed the basis evaluating the early photochemical gridded Eulerian Airshed Models used in acid deposition (RADM) and ozone (UAM) assessments. Landmark campaigns in the United States through the 1980's and 1990's such as the Southern California Air Quality Study (SCAQS; Lawson, 1990), the San Joaquin Valley Air Quality Study (SJAQS)/Atmospheric Utility Signatures, Predictions, and Experiments (AUSPEX; Roth, 1988) and the Southern Oxidant Study (Cowling and Furiness, 2000) were reviewed as part of the 2000 NARSTO ozone assessment (Solomon et al, 2000). Over the last decade there have been a series of field campaigns focusing on characterization of surface level aerosols through the PM Supersites program (Solomon et al. 2007). While the early campaigns focused on urban environments, the Eulerian Model Evaluation Field Study (EMEFS) and SOS during the early 1990s shifted focus toward regional spatial scales consistent with the dominant air pollution concerns (acid rain and ozone) of the time. In addition to addressing urban areas of concern such as Houston, Texas and Los Angeles, CA; more recent campaigns have extended spatial scales beyond regional studies to address oceanic transport and a variety of air pollution issues across the Northern Hemisphere, recognizing the importance of far ranging source regions and continental scale atmospheric processes. Some of these campaigns include local and regional studies for the northeast and southeast U.S., portions of Texas, and central and southern California; intercontinental studies including those for transport across Atlantic, Pacific, and Indian Ocean areas. A variety of federal (especially NOAA and NASA) and State entities have served as lead agencies for these studies. Table 3 provides a listing of studies conducted since the mid-1990s with well known campaigns as far back as the 1960s identified in footnotes. Earlier 20th century historical studies are not addressed.

A synthesis of key findings and lessons learned from major field campaigns conducted over the last two decades would elevate exposure of these programs to a wider audience potentially generating support to enhance and sustain atmospheric process and model evaluation studies which are important complements to routine ground based and satellite observation platforms. While the NARSTO data base (http://eosweb.larc.nasa.gov/PRODOCS/narsto/table_narsto.html) provides access to raw data for various field campaigns, coverage of campaigns beyond North America must be acquired from other sources. NASA's Atmospheric Data Science Center (http://eosweb.larc.nasa.gov/) also provides access to some of the more recent field campaigns. These web services would benefit potential users by providing intermediate descriptions of the scopes (locations, time frames, measurement systems and models) of these campaigns, including key objectives and findings.

TABLE 3. AIR MONITORING NETWORKS / CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES[3,4]

Network	Lead Agency[1]	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data	Notes
Texas Air Quality Study II (2005 - 2006)	Texas	17	2006	O3, NOx, NOy, SO2, Haze, Visibility, CO, VOC, Solar Radiation, Surface Meteorology, Upper Air	http://www.utexas.edu/research/ceer/texaqsII/PDF/12-12-04_Projected_Surface Sites_tbl.pdf	Researchers from universities, state and federal agencies, private industry, and local governments are joining forces to conduct a major field study to address air quality issues in the eastern half of Texas. The study, planned for a period extending from April 2005 through October 2006, will examine regional ozone formation, transport of ozone and ozone precursors, meteorological and chemical modeling, issues related to ozone formation by highly reactive emissions, and particulate matter formation. It is anticipated that the information from the study will be the scientific basis used for developing State Implementation Plans (SIPs) for ozone (with concentrations averaged over 8 hours), regional haze, and, if necessary, for fine particulate matter (particulate matter less than 2.5 microns in diameter, $PM_{2.5}$
2006 Texas Air Quality Study/ Gulf of Mexico Atmospheric Composition and Climate Study (TexAQS/GoMACCS)	NOAA	1 ship, 2 aircraft	2006	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/2006/	For TexAQS 2006, the NOAA air quality component will investigate, through airborne and sea-based measurements, the sources and processes that are responsible for photochemical pollution and regional haze during the summertime in Texas. The focus of the study will be the transport of ozone and ozone precursors within the state and the impact of the long-range transport of ozone or its precursors.
Intercontinental Chemical Transport Experiment - North America (INTEX-B) -- Intercontinental Transport and Chemical Transformation (ITCT/IGAC)	NOAA	3 aircraft	2006	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude -- NOAA aircraft	http://cloud1.arc.nasa.gov/intex-b/	The export of air pollutants from urban to regional and global environments is a major concern because of wide-ranging potential consequences for human health, cultivated and natural ecosystems, visibility degradation, weather modification, changes in radiative forcing, and tropospheric oxidizing capacity. During the spring of 2006 a highly integrated atmospheric field experiment was performed over and around North America. The Megacity Initiative: Local and Global Research Observations (MILAGRO), http://www.eol.ucar.edu/projects/milagro/ , resulted through a highly coordinated collaboration between NSF (through MIRAGE-Mex), DOE (through MAX-Mex), NASA (through INTEX-B) and a variety of research institution in the U.S. and Mexico and involved ground and air borne activities centered on Mexico City, Mexico during March 2006. MILAGRO goals were greatly facilitated and enhanced by a number of concurrent and coordinated national and international field campaigns and global satellite observations. After MILAGRO, NASA continued investigating this issue, this time focusing on the influence of Asian pollutants on North America, through a second airborne field element of INTEX-B in collaboration with NSF and NCAR. The integrated goals of MILAGRO and INTEX are: -To study the extent, persistence, and transformation of Mexico City pollution plumes; -To relate atmospheric composition to sources and sinks; -To quantify radiative properties and effects of aerosols, clouds, water vapor & surfaces; -To map anthopogenic and biogenic emissions; -To characterize transport and evolution of Asian pollution to North America and beyond and determine implications for regional air quality and climate; -To achieve science-based validation of satellite observations of troposheric composition

TABLE 3. AIR MONITORING NETWORKS / CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

Intercontinental Chemical Transport Experiment - North America (INTEX-NA) -- Intercontinental Transport and Chemical Transformation (ITCT/IGAC)	NOAA	aircraft, sondes, satellites	2004	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude -- NOAA aircraft	http://cloud1.arc.nasa.gov/intex-na/desc.html	INTEX-NA is an integrated atmospheric field experiment performed over and around North America. It seeks to understand the transport and transformation of gases and aerosols on transcontinental/intercontinental scales and their impact on air quality and climate. A particular focus in this study is to quantify and characterize the inflow and outflow of pollution over North America. The main constituents of interest are ozone and precursors, aerosols and precursors, and the long-lived greenhouse gases. INTEX-NA is part of a larger international ITCT (Intercontinental Transport and Chemical Transformation) initiative. INTEX-NA goals are greatly facilitated and enhanced by a number of concurrent and coordinated national and international field campaigns and satellite observations. Synthesis of the ensemble of observations from surface, airborne, and space platforms, with the help of a hierarchy of models is an important goal of INTEX-NA.
New England Air Quality Study (NEAQS) -- Intercontinental Transport and Chemical Transformation (ITCT) 2004	NOAA	4 site, 1 ship, 2 aircraft, profiler network	2004	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/2004/	NOAA continues a joint regional air quality and climate change study combining elements of the previous NEAQS study and the Intercontinental Transport and Chemical Transformation (ITCT) research activity to focus on air quality along the Eastern Seaboard and transport of North American emissions into the North Atlantic. The major NOAA assets (the two aircraft and the ship) are deployed in a manner that supports the objectives of both components.
East Tennessee Ozone Study (ETOS)	NOAA	15+	2003	O3, Surface Meteorology	http://www.atdd.noaa.gov/etos.htm	ETOS 2003 developed a regional ozone database to include both mean hourly averages and hourly histograms of individual measurement readings. The 2003 study period (based on scoping studies 1999 - 2002) provides a regional view to supplement Tennessee's regulatory network and serves as a demonstration and evaluation/validation database for various operational and developmental air quality forecast model components. The full scope of ETOS 2000 is continuously under planning and review, and is refined each year using the previous year's analysis and experience to focus on particular issues within the East Tennessee region.
Texas Air Quality Study (TexAQS) 2000	Texas	~20	2002	O3, NOx, PM2.5/PM10, CO, SO2, VOCs, Surface Meteorology	http://www.utexas.edu/research/ceer/texaqs/visitors/about.html	The study is designed to improve understanding of the factors that control the formation and transport of air pollutants along the Gulf Coast of southeastern Texas. Six weeks of intensive sampling, including measurements of gaseous, particulate, and hazardous air pollutants, are made at approximately 20 ground stations, located throughout the eastern half of the state. Experts in meteorology, atmospheric chemistry, and other areas of science study the formation, composition, and day-night cycles of ozone and particulate matter, as well as how these pollutants are affected by weather.
Texas Air Quality Study (TexAQS) 2000 Field Campaign	NOAA	2 aircraft	2002	O3, CO, CO2, SO2, NO, NO2, NOy, PAN, HNO3, NH3, VOCs, Solar Radiation, Meteorological Parameters, aerosols	http://www.utexas.edu/research/ceer/texaqs/visitors/about.html	Additional sampling in TexAQS 2000 is carried out with specially equipped aircraft that can detect air pollutants very quickly, at very low concentrations.

TABLE 3. AIR MONITORING NETWORKS / CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

Bay Region Atmospheric Chemistry Experiment (BRACE)	NOAA	1 aircraft	2002	NO3, NH4, O3, SO2, NOx, CO, trace metals, particulates	http://www.dep.state.fl.us/secretary/news/2002/02-039.htm	The Florida Department of Environmental Protection (DEP), with the support of a team of federal, state, local, university and private scientists (including NOAA) conducted a month-long series of intensive studies to determine the level of influence of nitrogen deposited into Tampa Bay from local and regional sources of air pollutants on water quality. During the Bay Region Atmospheric Chemistry Experiment (BRACE), NOAA operated a research aircraft over the Tampa Bay region to collect air quality measurements of the many atmospheric forms of nitrogen and related pollutants that may potentially influence the water quality of Tampa Bay.
New England Air Quality Study (NEAQS) 2002 -- AIRMAP	NOAA	4	2002	O3, NOx, NOy, SO2, CO, VOCs, PM2.5, Precipitation Chemistry, Surface Meteorology	http://airmap.unh.edu/data/	AIRMAP is a research program focused on atmospheric chemical and physical observations in rural to semi-remote areas of New Hampshire with the goal of understanding inter-relationships in regional air quality, meteorology, and climatic phenomena. Research goals are to: (1) document and analyze current trends in the regional air quality of New England which is affected by transport from upwind regions of the U.S. and Canada and by local emission sources; (2) document and analyze current and past (the last 100 years) synoptic-to-local meteorological patterns, features, and extreme events in New England; and (3) numerically simulate the coupled evolution of atmospheric transport and chemistry in New England using various modeling tools.
New England Air Quality Study (NEAQS) 2002	NOAA	1 ship, 2 aircraft	2002	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/NEAQS/	The NOAA component of this multi-institutional effort addresses the analysis of existing climate data, and the development of new air quality monitoring programs. A background of information is to be developed that addresses New England's changing climate and air quality so as to improve understanding of the relationship between air quality and weather and determine the causes of climate change in New England
Intercontinental Transport and Chemical Transformation (ITCT) 2002 Activities	NOAA	1 site, 1 aircraft	2002	CO2, CO, CH4, SO2, O3, SF6, N2O, CFCs, Aerosols, Solar Radiation, Surface Meteorology & Upper Air -- surface. O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air -- aircraft	http://esrl.noaa.gov/csd/ITCT/2k2/	This field program, scheduled for spring 2002 to investigate the composition of air masses along the Pacific coast of North America, is part of the Intercontinental Transport and Chemical Transformation (ITCT) research activity of the International Global Atmospheric Chemistry Program (IGAC) Program. Goals of this field study are to: characterize the chemical composition of the air masses coming ashore at the West Coast; explore the composition of these air masses as they are transported inland; and investigate the alteration in composition associated with the addition of emissions from U.S. West Coast sources. The NOAA WP-3D aircraft is to deploy a wide array of instrumentation for the in situ measurement of gaseous and aerosol parameters plus radiation and remote aerosol sensing by LIDAR. The Trinidad Head baseline observatory characterizes chemical composition of marine boundary layer at the U.S. West Coast and provides linkage between composition measurements and radiative properties of the aerosols. The NOAA ETL Laboratory network of 915-MHz radar wind profilers that are deployed in California provide additional meteorological information.

TABLE 3. AIR MONITORING NETWORKS / CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

TRAnsport and Chemical Evolution over the Pacific (TRACE-P)	NASA	2 aircraft	2001 (2 months)	O3, NO, NO2, N2O, CH4, SO2, NH3, CO, CO2, aerosols, PAN, HNO3, aldehydes, peroxides, speciated hydrocarbons, other pollutants, meteorological parameters	http://www-gte.larc.nasa.gov/gte_fld.htm#TRACE	TRACE-P is part of a series of aircraft missions aimed at better understanding of global tropospheric chemistry, and more specifically in this case, the effects of outflow from the Asian continent on the composition of the global atmosphere. Objectives are to determine: (1) pathways for outflow of chemically and radiatively important gases and aerosols, and their precursors, from eastern Asia to the western Pacific; and (2) the chemical evolution of the Asian outflow over the western Pacific, and the ensemble of processes that control this evolution. Approximately 20 aircraft measurement flights involving horizontal and vertical profiles for a total of over 300 hours were supported by surface based measurements and soundings.
Aerosol Characterization Experiments - Asia (ACE-Asia)	NSF	sites, ships, aircraft, satellites	2001 (spring)	aerosol chemical, physical, and radiative properties and radiative fluxes, meteorological parameters	http://saga.pmel.noaa.gov/Field/aceasia/ACEAsiaDescription.html	The Aerosol Characterization Experiments (ACE) are designed to increase understanding of how atmospheric aerosol particles affect the Earth's climate system. ACE-Asia took place during the spring of 2001 off the coast of China, Japan and Korea which includes many types of aerosol particles of widely varying composition and size. These particles include those emitted by human activities and industrial sources, as well as wind-blown dust. Data from ACE-Asia is improving understanding of how atmospheric aerosols influence the chemical and radiative properties of the Earth's atmosphere.
Central California Ozone Study (CCOS)[2]	California	100+ sites, 6 aircraft, profilers, sondes	2000	O3, VOC, NOx, NO, NOy, CO, PM10, PM2.5, solar radiation, surface meteorology, upper air	http://www.bayareamonitor.org/may00/air3.html	For the summer season, this study collected meteorological and air quality data for the central section of California in 2000. Planes and weather balloons collected data at ground level and aloft. The data collected is used to improve the understanding of the role of meteorology on the formation and behavior of air pollutants and their precursors and emission sources and patterns. The information gathered will be used to develop an improved modeling system that will be used in preparing plans to attain the new federal 8-hour ozone standard, as well as to update the Clean Air Plan to attain the state ozone standard.
California Regional Particulate Air Quality Study (CRPAQS)[2]	California	~60	1999 to 2001	PM2.5, PM10, nephelometer, with some sites adding SO4/NO3, OC/EC, NO2, NOy, PAN, SO2, surface meteorology	http://www.narsto.org/section.src?SID=9	The California Regional PM10/PM2.5 Air Quality Study is a comprehensive public/private sector collaborative program to provide an improved understanding of particulate matter and visibility in central California. It is intended to evaluate both the national and State air quality standards for PM10 and PM2.5. The field programs consisted of 14 months of monitoring throughout the San Joaquin Valley (SJV) and surrounding regions, as well as intensive monitoring during summer, fall, and winter seasonal periods.
Southern Oxidant Study (SOS) 1999 Field Campaign -- Nashville	NOAA	3 sites, 4 aircraft	1999	O3, NO, NO2, NOy, VOCs, aerosols, Surface Meteorology & Upper Air (profiler), ozonesonde -- surface O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude -- aircraft	http://esrl.noaa.gov/csd/SOS99/	The Southern Oxidants Study (SOS), in collaboration with other organizations and programs, conducted this major Field Campaign during June/July 1999. The Nashville/Middle Tennessee region measurements focused on an improved understanding of the processes that control the formation and distribution of fine particles and ozone. Three study themes were: Local vs. regional contrasts, Ozone and PM formation in plumes, and diurnal cycle in chemistry and meteorology. These themes were addressed through a series of coordinated measurements involving instrumented aircraft and a ground-based network of chemistry and meteorological measurements.

TABLE 3. AIR MONITORING NETWORKS / CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

PM Supersite Program	EPA	2 Phase I Sites 7 Phase II Sites	1999	Measurement may include: PM2.5, PM10, TSP, SO4, NO3, EC, OC, light absorption & extinction, O3, CO , NOx, NO, NO2, NOy, HNO3, NH3, VOCs, Carbonyls, PAH, major ions and elements, surface and upper air meteorology	http://www.epa.gov/ttn/amtic/supersites.html	In response to Executive and Congressional mandates and recommendations from the National Research Council a "Supersites Conceptual Plan" was developed and implemented. Atlanta and Fresno were selected as initial Phase I sites and as a result of a competitive process Baltimore, Fresno, Houston, Los Angeles, New York, Pittsburgh, and St. Louis were selected for Phase II. Goals generally were to characterize particulate matter, support health effects and exposure research, and conduct methods testing. Extensive monitoring, data analysis, and publication continued to 2005 with the preparation of a Final Report for each city.
Big Bend Regional Aerosol and Visibility Observational (BRAVO) Study	NPS/EPA	38 fixed, 6 tracer sites	1999	SO2, SO4, PM2.5, NO3, NH4, major ions and elements, nephelometer, transmissometer, meteorological parameters & upper air, PFC tracer	http://www.dri.edu/Home/Features/text/BRAVO.htm	The BRAVO study was conducted for four months during 1999 with the primary objective of identifying the causes of haze in the Big Bend National Park located in West Texas. This very large, collaborative study enlisted numerous participants with sponsorship from federal/State agencies, private industry, and research organizations. The BRAVO study utilized data from a 38-site network to characterize spatial and temporal aerosol patterns in the atmosphere. In addition, upper-air measurements and extensive optical measurements of light scattering and absorption were made. Because monitoring and source characterization activities were conducted only in the United States, the study design included additional monitoring and tracer studies along the U.S./Mexican border.
Indian Ocean Experiment (INDOEX)	UCSD	6 sites, 2 ships, 5 aircraft, satellites	1999 (4 months)	O3, NO, NO2, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, trace gases, aerosols, meteorological parameters & upper air	http://www-indoex.ucsd.edu/	The Indian Ocean Experiment (INDOEX) addresses questions of climate change through collection of in-situ data on the regional cooling effect of sulfate and other aerosols. The project's goal is to study natural and anthropogenic climate forcing by aerosols and feedbacks on regional and global climate. INDOEX field studies occur where pristine air masses from the southern Indian Ocean including Antarctica and not-so-clean air from the Indian subcontinent meet over the tropical Indian Ocean to provide a unique natural laboratory for studying aerosols. Scientists collect data from the water surface through the lower stratosphere, on the aerosol composition, reactive atmospheric gases, solar radiation fluxes, wind and water vapor distribution. To this end, investigators use multiple aircraft, ships and island stations over the Arabian Sea and the Indian Ocean.
Eulerian Model Evaluation Field Study (EMEFS)	Canada	~135	1998	O3, NO2, SO2, NH3, HNO3, major ions,	http://www.msc-smc.ec.gc.ca/natchem/particles/n_emefs_e.html	Under EMEFS, air and precipitation chemistry data were collected daily for two years over much of the eastern United States and Canada to provide data for assessing the performance of acid deposition and other regional scale models.
NARSTO-Northeast 1995	Multiple	559	1995	O3, NO, NOx	http://www.narsto.org/section.src?SID=9	Measurements were made during the NARSTO-Northeast 1995 intensive field campaign during the period May through September. One-hour average O3, NO, and NOX measurement results are reported for ground surface monitoring stations operated by various agencies including EPA AIRS, CASTNet, ESE, Harvard University, NYSEG, PEPCO, and the University of Maryland.

TABLE 3. AIR MONITORING NETWORKS / CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

SOS Nashville/Middle Tennessee Ozone Study	TVA	116	1994-1995	O3, SO2, NO, NOy, and CO, VOC, Surface Meteorology, rawinsonde and ozonesonde releases, and a radar profiler/radar acoustic sounding system. -- surface Airborne ozone and aerosol lidar – aircraft	http://www.ncsu.edu/sos/pubs/sos2/State_of_SOS_2.pdf	This ozone-focused field study was carried out in the 11-state region surrounding Nashville/Middle Tennessee, beginning with a 3-week exploratory study during the summer of 1994 and culminating in a six-week field measurement campaign June/July 1995. Measurements were taken at 116 ground-based and tall building and tower-based chemical and meteorological measurement sites and a series of six airborne chemical measurement platforms. The most significant feature of the Nashville/Middle Tennessee Ozone Study was a coordinated series of 40+ aircraft studies to measure physical and chemical characteristics of urban and industrial plumes. (Note: an earlier ozone-focused set of field studies was also conducted in the Atlanta, GA area during the summers of 1990 - 1992.)
North Atlantic Regional Experiment (NARE)	NOAA	various sites, 1 ship	1993	O3, NO, NO2, NOx, NOy, VOC, Surface Meteorology	http://www.igac.noaa.gov/newsletter/24/introduction.php	The NARE program measured the type and amount of air pollutants being transported from the North American continent to the Northern Atlantic Ocean. Since the Northeast United States and Nova Scotia, Canada are the last land locations as air masses move out over the ocean, measurements were made a number of land and island sites in Maine, Nova Scotia, and Sable Island. Acadia National Park participated in this study

Footnotes:

1. EPA -- Environmental Protection Agency
   NASA -- National Aeronautics and Space Administration
   NOAA -- National Oceanic and Atmospheric Administration
   NPS -- National Park Service
   NSF -- National Science Foundation
   UCSD -- University of California San Diego (Scripts Institution of Oceanography)

2. This study is part of the Central California Air Quality Studies (CCAQS) which comprise the California Regional Particulate Air Quality Study (CRPAQS) and the Central California Ozone Study (CCOS). CCAQS is a multi-year effort of meteorological and air quality monitoring, emission inventory development, data analysis, and air quality simulation modeling. Prior studies in California included: Southern California Ozone Study (SCOS97) -- 1997; Integrated Monitoring Study (IMS95) -- 1995; San Joaquin Valley Air Quality Study (SJVAQS) -- 1990; SARMAP Ozone Study -- 1990; Southern California Air Quality Study (SCAQS) -- 1987.

3. Historically, there have been many other field studies in the 1960's - 1990's that are not reflected in this table that involve both fixed monitoring sites and aircraft; well known examples include Regional Air Pollution Study (RAPS), Large Power Plant Effluent Study (LAPPES), Northeast Corridor Regional Modeling Program (NECRMP), Northeast Regional Oxidant Study (NEROS), Persistent Elevated Pollutant Episode (PEPE), and Lake Michigan Ozone Study (LMOS).

Section 2.1.3 Air Monitoring Networks for Climate Forcing, Transport, and Stratospheric Ozone

To identify a baseline for pollutant concentrations, particularly those that may have climate effects, NOAA has been the lead federal agency in establishing the necessary monitoring networks. For most of these networks the emphasis has been on long-term measurements, beginning as early as 1957, for carbon dioxide, methane, aerosols, halogenated compounds, other pollutants and meteorological measurements at several core surface sites (Table 4). With the assistance of other federal agencies and universities, additional networks provide a variety of measurement platforms (including additional fixed surface sites, aircraft, remote sensing and towers) to supplement information on the spatial and vertical distribution of these pollutants.

In addition, since the mid-1990s some routine international airline flights have been used to provide measurements along their flight paths (horizontal and vertical) for pollutants primarily oriented to ozone and carbon products. Recently, NOAA has developed a plan to deploy 12 "tall towers" across the United States to assess atmospheric carbon budgets. The towers (http://www.esrl.noaa.gov/gmd/ccgg/towers/index.html) will include measurements of carbon dioxide, CO and other trace indicator gases, and will serve as a ground based evaluation component for NASA's orbiting carbon observatory (OCA) scheduled to be deployed in 2008.

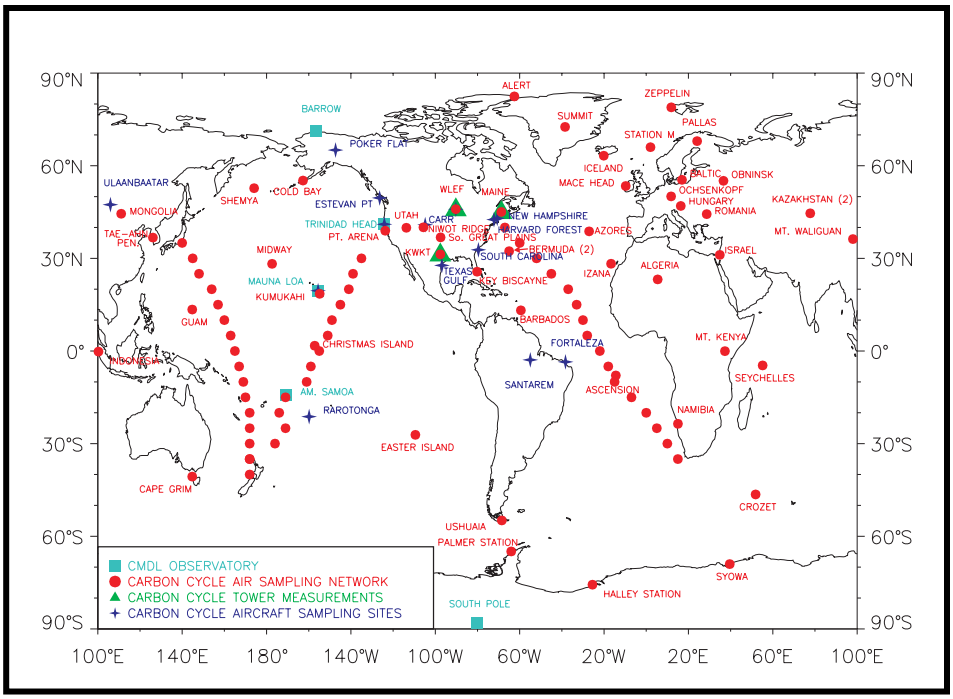

Figure 11. Surface based locations and aircraft routes for NOAA's routine carbon dioxide sampling program.

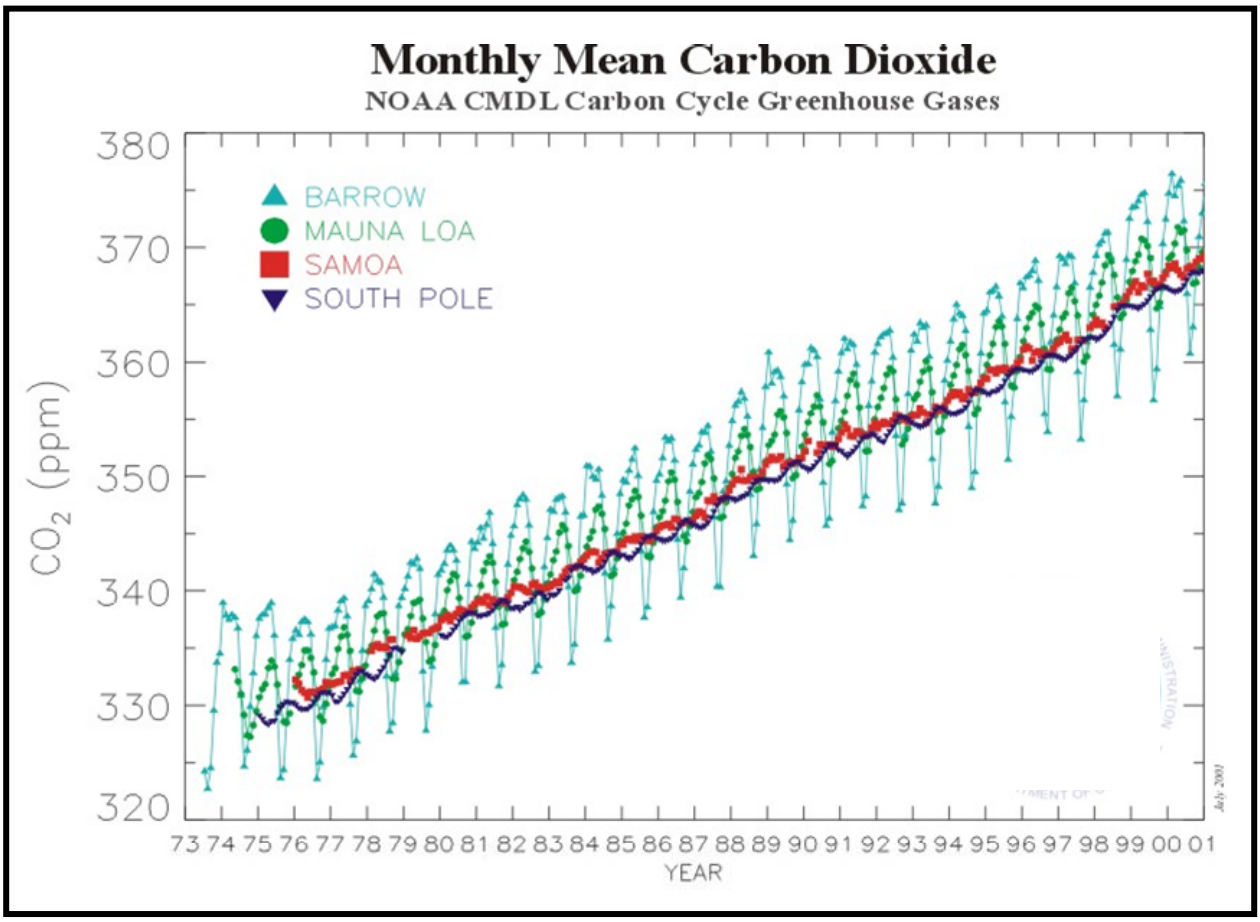

Figure 12. Figure 12. Carbon dioxide trends based on long term surface monitoring platforms (source, Pieter Toms, NOAA).

TABLE 4.
AIR MONITORING NETWORKS FOR CLIMATE FORCING, TRANSPORT, AND STRATOSPHERIC OZONE

Network	Lead Federal Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Global Monitoring Division Baseline Observatories					
Mauna Loa	NOAA	1	1957	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/MLO/
Point Barrow	NOAA	1	1973	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/BRW/
Samoa	NOAA	1	1974	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/smo/
South Pole	NOAA	1	1957	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/SPO/
Trinidad Head	NOAA	1	2002	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/THD/
Global Monitoring Division -- Carbon Cycle Greenhouse Gases Group (CCGG)					
Observatory Measurements	NOAA	4	1957	See above baseline observatories	http://www.cmdl.noaa.gov/ccgg/insitu.html
Cooperative fixed sites	NOAA	62	1967	CO2, CH4, CO, H2, N2O, and SF6, stable isotopes of CO2 and CH4	http://www.cmdl.noaa.gov/ccgg/flask.html
Commercial Ships	?????	?????	?????		
Others					
ALE / GAGE / AGAGE Network	NASA	5 Current 2 Discontinued	1978	CO, CH4, SF6, N2O, H2, CFCs, HCFCs, HFC's, methyl chloroform, carbon tetrachloride, chloroform, perchloroethylene, halons & others	http://cdiac.ornl.gov/ndps/alegage.html
Tall Tower Measurements	NOAA	3	1992	CO2, CO, CH4, H2, CFCs, methyl chloroform, carbon tetrachloride, chloroform, sulfur hexafluoride, perchloroethylene	http://www.cmdl.noaa.gov/ccgg/towers.html
Aircraft Measurements	NOAA	16 airport sites	1992	CO2, CH4, N2O, CO, H2, SF6	http://www.cmdl.noaa.gov/ccgg/aircraft.html
Networks for Halogenated Gases and Ozone	NOAA	Multiple platforms	1986	nitrous oxide (N2O), CFCs, HCFCs, HFCs, CH3Br, CH3Cl, CH3I), halons	http://www.cmdl.noaa.gov/hats/
Network for Aerosols	NOAA	Multiple platforms	mid-1970s	light absorption, total scattering and backscattering	http://www.cmdl.noaa.gov/aero/
North American Aircraft and Tall Tower Carbon Observing System	NOAA	10 Aircraft 3 tall towers	1992	CO, CO2, CH4	http://www.cmdl.noaa.gov/carbonamerica/
North American Carbon Program Atmospheric Observing System	Multiple participants	Multiple platforms	2001	CO, CO2, CH4	http://www.nacarbon.org/nacp/
AERONET -- AErosol RObotic NETwork	NASA	22+ other participants	1998	Aerosol spectral optical depths, aerosol size distributions, and precipitable water	http://aeronet.gsfc.nasa.gov/index.html

TABLE 4.
AIR MONITORING NETWORKS FOR CLIMATE FORCING, TRANSPORT, AND STRATOSPHERIC OZONE
(continued)

Cheeka Peak Observatory	None	1	1997	O3, CO, Aerosols, Solar Radiation, Surface Meteorology	http://research.uwb.edu/jaffegroup/modules/cpo_plot/
Mt. Bachelor Observatory	None	1	2004	O3, CO, NO/NO2, Aerosols, Hg, Surface Meteorology	http://research.uwb.edu/jaffegroup/modules/mbo_plot/
International Aircraft Measurements					
MOZAIC (Measurement of ozone, water vapour, carbon monoxide and nitrogen oxides aboard Airbus in-service aircraft)	None	2500 Airbus international flights/year	1994	O3, H2O, CO, NOx	http://www.fz-juelich.de/icg/icg-ii/mozaic/home
NOXAR (Measurements of Nitrogen Oxides and Ozone Along Air Routes)	None	500 Swiss Air flights to U.S. and far east	1995 - 1996	O3, NO, NO2	http://www.iac.ethz.ch/en/research/chemie/tpeter/Noxar.html
CARIBIC (Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container)	None	~100 Lufthansa flights	1997	CO, O3, CO, CH4, CO2, N2O, SF6, NMHC, Position & Meteorology and Cloud cover.	http://www.caribic-atmospheric.com/
AMATRAS (Atmospheric Measurement by Airliners for Trace Species)	None	262 flights between Japan and Australia	1993	CO2, CH4, CO and SF6	http://www.jal.com/en/press/0000336/img/AMATRAS.pdf

Section 2.1.4 Observation Systems Providing Vertical Profile Information

A variety of measurement systems, some redundant with systems identified in previous sections, are used to obtain vertical profiles of pollutant and meteorological information from hundreds to thousands of feet in the vertical (Table 4, Appendix A). NOAA and NASA are the lead federal agencies for these systems which include aircraft, sondes, remote sensing, and towers dating from the 1990s. Measurements generally focus on ozone, aerosols, climate forcing pollutants, and meteorological parameters which affect the mixing and transport of pollutants. Routine international aircraft measurements are again reflected, but especially of note are NOAA aircraft and ship platforms and their extensive instrumentation for monitoring pollutants and meteorological parameters. Vertical profile measurements are addressed in Section 3 as key linkage observations (1) between ground based and remote satellite platforms and (2) enabling integration of observations and modeling systems.

Section 2.1.5 National Routine Meteorological Monitoring Networks

Networks for meteorological measurements have a long history in the United States and are summarized in Table 5, Appendix A. The Automated Surface Observing System (ASOS) is a relatively recent replacement (beginning in 1992) for weather observer based programs long used by NOAA (and predecessor agencies), and also by the military services, to obtain hourly (or more frequent) meteorological measurements. The hundreds of ASOS sites are supplemented by an even more extensive Cooperative Observer Program (extending back to the 1890's) with daily measurements. Together these networks provide a long record of weather data which includes wind, temperature, humidity, precipitation, visibility, cloud cover, pressure, indications of severe weather, etc. Upper Air Stations, also with a long history extending to the 1930s, provide twice-daily vertical measurements of wind, temperature, humidity and pressure at about 100 locations. NOAA (as the lead federal agency for these networks) also operates other networks that provide complementary measurements of meteorological parameters, whether as part of the regular weather network or for special purpose studies. These latter networks include (1) radar to measure precipitation and winds, (2) profilers for remote sensing of the vertical distribution of winds and temperature, (3) buoys for measuring surface-based meteorological parameters in marine environments, (4) satellites to measure clouds and vertical profiles of temperature, moisture and wind, and (5) instrumented commercial aircraft to measure wind and temperature. These latter networks of more sophisticated measurements were generally initiated in the 1980s and 1990s, although they may have been preceded by earlier systems, e.g., weather radar and satellites date to the 1960s.

Networks that also provide measurements of various meteorological parameters at thousands of locations are operated by DOA, EPA, and State/local/tribal agencies to respectively support agricultural and air pollution control programs.

PBL height (mixed layer height) is a derived quantity based largely on vertical temperature profiles and refractive index structure parameters, Cn^2. Relevant observed indicators of PBL depth include aerosol and gaseous chemistry profiles.

Observations for evaluating PBL heights. PBL height (mixed layer height) is a derived quantity based largely on vertical temperature profiles and refractive index structure parameters, Cn^2. The Meteorological Data Ingest System (MADIS - http://madis.noaa.gov/) is an integrated system incorporating observations from a variety of surface based, vertical profile

and satellite networks that provides a centralized source of observations servicing evaluation efforts. The deployment of NOAA's profiler network (NPN - http://www.profiler.noaa.gov/npn/) over the last decade has added near continuous stream of wind vector data to complement the National Weather Service's (NWS) radiosonde network providing twice daily soundings spread across nearly 100 locations throughout the United States. The NPN includes 35 unmanned Doppler Radar sites profiling the troposphere (10-15 km) and concentrated in the central United States designed for violent weather forecasting. The Photochemical Assessment Measurement Stations (PAMS) program supports ~20 radar profilers that provide highly resolved wind profiles and Cn^2 coefficients of the boundary layer (up to 5 km). The boundary layer radar profilers, especially when complemented by temperature profiles generated by Radio-Acoustic Sounding System (RASS) offer a source of relatively untapped data for model evaluation.

The radiosonde network lacks adequate temporal resolution to adequately characterize diurnal development and collapse of PBL heights. Radar profilers are an underutilized resource which has inadequate spatial coverage and lacks a consensus methodology to synthesize raw data into spatial and temporal observation patterns conducive to model evaluation. Cloud height measurements through ceilometers are reasonable PBL depth indicators for non clear sky conditions, but a spatially extensive network for broad application is not available. Since 2004, over 400 commercial aircraft have been collecting meteorological variables (temperature, pressure, RH, winds) as a part of the tropospheric Airborne Meteorological Data Reporting (TAMDAR - http://www.airdat.com/./tamdar/index.php) system. While TAMDAR is designed to provide near real time data for forecasting, the system provides valuable vertical profile temperature data (and other variables) during ascents and descents that potentially can be synthesized to fill in temporal and spatial gaps of ground based profilers.

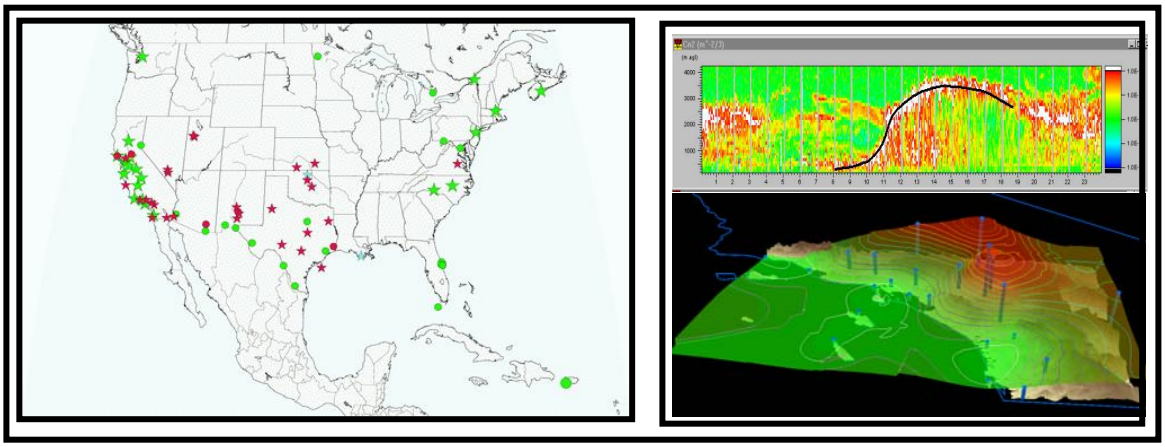

Figure 13. Left - North American air quality profiler network (**http://www.madis-fsl.org/cap/profiler.jsp**), right – example of boundary layer reconstruction using Cn^2 reflectivity coefficients Southern California (1500 PST, 9/3/1997, courtesy, McClinton, STI).

Section 2.1.6 Ground based solar radiation networks.

Full spectrum and specific solar radiation wavelength measurements provide important data used for characterizing energy budgets for meteorological models and climate change assessments, atmospheric column aerosol light scattering, and as direct indicators of UV radiation exposures relevant to human, agricultural and ecosystem health. Accordingly, a

variety Federal agencies including NOAA, NASA, EPA, USDA and the NPS all have participated in a variety of measurement programs (Table 5).

The AErosol RObotic NETwork (AERONET) is a collaborative global network of Sun Photometers (Figure 13) organized by NASA providing ground based aerosol optical depth (AOD) estimates used primarily to evaluate space based aerosol measurements. NOAA's Surface Radiation Budget Network (SURFRAD) is part of the global Base Line Surface Radiation (BASR) Network and is an important surface complement to satellites and used for characterizing surface energy balances and supporting a variety of global scale climate models.

The Brewer UV spectrophometer networks started in 1994 with EPA's UVNet program and included over 20 sites until funding was eliminated in 2004. A subset of six sites (Figure 13) supported by EPA and NOAA is operating as the NOAA-EPA Brewer Spectrophotometer UV and Ozone Network (NEUBREW). These UV networks have been motivated by a range of effects ranging from skin cancer to forest and crop productivity. Interest in characterizing association between changes in stratospheric ozone and attenuation of UV reaching the surface has provided some residual EPA funding support. The Brewer instruments are capable of providing total column ozone and SO_2 estimates, which potentially can provide ground based complements to satellite total column data.

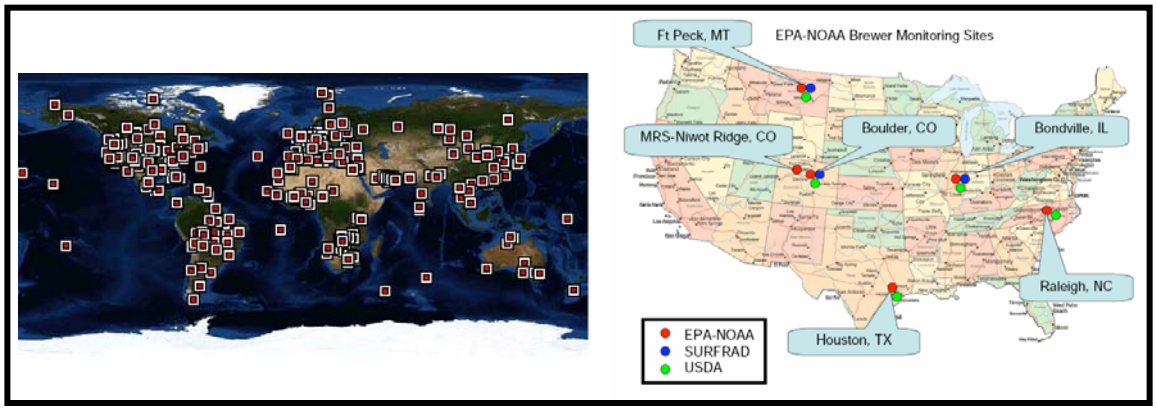

Figure 14. AERONET sun photometer (left) and UV Brewer networks.

TABLE 5. Solar Radiation Networks

Network	Lead Federal Agency	Number of Sites	Initiated/ Terminated	Measurement Parameters	Location of Information and/or Data
UV Index -- EPA Sunrise[1] Program	EPA	~50 U.S. cities	2002	Calculated UV radiation index	http://www.epa.gov/sunwise/uvindex.html
UV Net -- Ultraviolet [2] [2]Monitoring Program	EPA	21	1995/2004	Ultraviolet solar radiation (UV-B and UV-A bands), Irradiance, ozone, NO2	http://www.epa.gov/uvnet/access.html
NEUBREW (NOAA-EPA Brewer Spectrophotometer UV and Ozone Network) [2]	NOAA	6	2005	Ultraviolet solar radiation (UV-B and UV-A bands), Irradiance, ozone, SO_2	http://www.esrl.noaa.gov/gmd/grad/neubrew/
UV-B Monitoring and Research Program	USDA	35	1992	Ultraviolet-B radiation	http://uvb.nrel.colostate.edu/UVB/jsp/uvb_climate_network.jsp
SURFRAD -- Surface Radiation Budget Network	NOAA	7	1993	solar and infrared radiation, direct and diffuse solar radiation, photosynthetically active radiation, UVB, spectral solar, and meteorological parameters	http://www.srrb.noaa.gov/surfrad/index.html
AERONET -- AErosol RObotic NETwork MPLNET – Micro-pulse Lidar Network	NASA co-located networks	22 + other participants 8	1998 2000	Aerosol spectral optical depths, aerosol size distributions, and precipitable water Aerosols and cloud layer heights	http://aeronet.gsfc.nasa.gov/index.html http://mplnet.gsfc.nasa.gov/
PRIMENet -- Park Research & Intensive Monitoring of Ecosystems NETwork [2]	NPS	14	1997	ozone, wet and dry deposition, visibility, surface meteorology, and ultraviolet radiation	http://www.forestry.umt.edu/research/MFCES/programs/primenet/

Footnotes:

1. Sunrise program estimates UV exposure levels through modeling - does not include measurements.

2. NEUBREW is subset Original UV brewer network (UV Net) , PRIMENET participated in UV Net program

Section 2.1.7 Satellite–Based Air Quality Observing Systems

[note: more descriptive explanation of satellite data use is provided relative to other sections as there has been rapid development of applications over the last decade and much]

An extensive array of satellite-based systems (Table 6) with the capability of measuring atmospheric column total species has been established by United States and European Satellite programs lead by NASA and NOAA in the United States and the European Space Agency (ESA). A suite of satellites including Aqua, Aura, CALIPSO, OCO, Glory, as well as NOAA-17, NOAA-18 and NPOESS, have either been launched since about the year 2000 or have other near-term proposed launch dates. Collectively, the remote sensing techniques for measuring columns and/or profiles of aerosols (AOD), O3, CO, CO2, CH4, SO2, nitrogen oxides, CFCs, other pollutants, and atmospheric parameters such as temperature and H2O. Most of these satellites have a near-polar orbit allowing for two passes per day over a given location. When taken together, a group of six satellites (Aqua, Aura, CALIPSO, OCO, as well as CloudSat and PARASOL) coined the A-Train is being configured to fly in a formation that crosses the equator a few minutes apart at around 1:30 local time to give a comprehensive picture of earth weather, climate and atmospheric conditions.

Satellite imagery offers the potential to cover broad spatial areas; however, an understanding of their spatial, temporal and measurement limitations is necessary to determine how these systems complement ground based networks and support air quality management assessments.

Temporal characterization. The near polar orbiting tracks of most satellites performing trace gas measurements provides wide spatial coverage of reasonable horizontal (10-50 km) resolution, but delivers only twice daily snapshots of a particular species. Consequently, temporal patterns of pollutants as well as a time-integrated measure of pollutant concentrations cannot be delineated explicitly through satellite measurements alone. The Geostationary satellite platforms such as the GOES systems in NOAA do provide near continuous coverage of physical parameters for weather tracking and forecasting purposes. There are proposed campaigns within NASA and across partnership Federal agencies to deploy geostationary platforms with measurement capabilities for trace gases and aerosols to enhance space based characterization of tropospheric air quality (Fishman et al., 2005).

Spatial Characterization. Polar orbiting satellites typically provide horizontal spatial resolution between 10 and 100km, depending on the angle of a particular swath segment. Spatial resolution less than 10km is possible with geostationary platforms. Characterization of elevated pollutants delivered by satellite systems complements of our ground based in-situ measurement networks – especially considering that a considerable fraction of pollutant mass resides well above Earth's surface. With few exceptions, Satellite data typically represents a total atmospheric column estimate. For certain important trace gases (e.g., NO_2, SO_2, HCHO) and aerosols, the majority of mass resides in the boundary layer of the lower troposphere, enabling associations linking column data to surface concentrations or emissions fields. For example, reasonable correlations, especially in the Eastern United States, have been developed between concentrations from ground level $PM_{2.5}$ stations and aerosol optical depths (AOD) from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Aqua and Terra satellites (Engel-Cox et al. 2004; Figure 14). The Infusing Satellite Data into Environmental Applications (IDEA, http://idea.ssec.wisc.edu/) site provides daily displays and

interpretations of MODIS and surface air quality data. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite (discussed below) provides some ability to resolve aerosol vertical gradients.

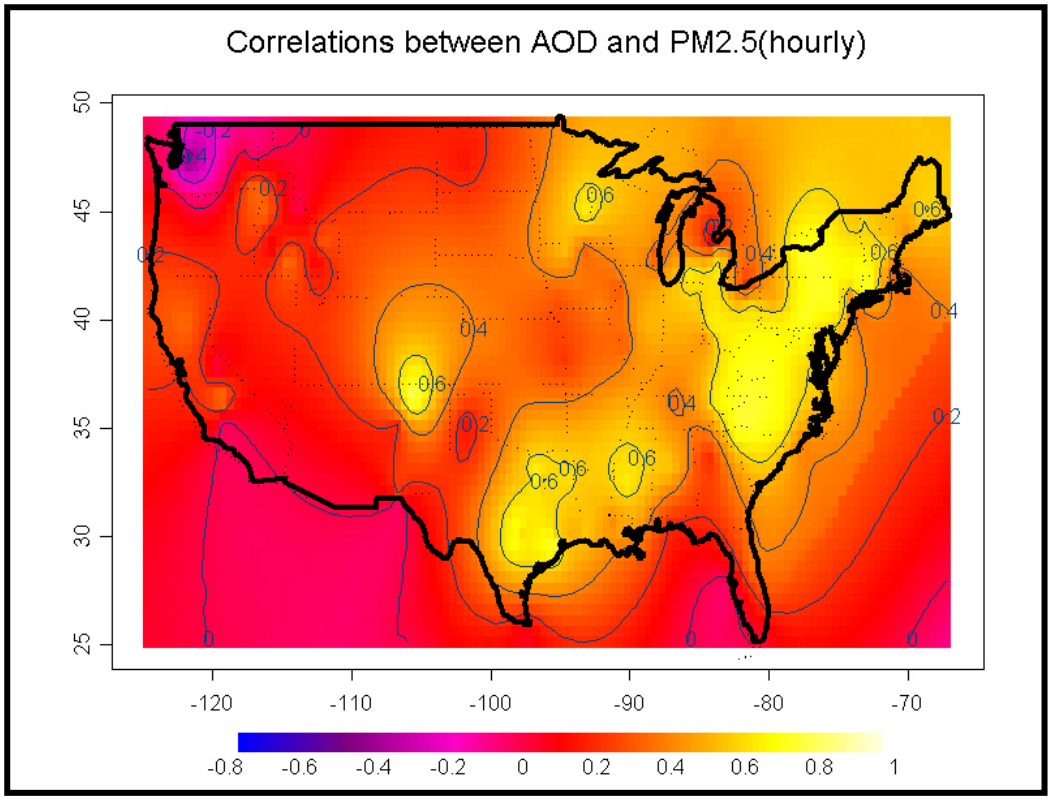

Figure 15. Correlation surfaces between MODIS AOD and hourly PM2.5 surface sites from April - September, 2002 (Engel-Cox, et. al, 2004).

In contrast to aerosols, most ozone resides in the stratosphere. Various techniques have been developed to extract the stratospheric signal to yield a tropospheric ozone residual (TOR), based on known homogeneities in the stratosphere and the use of chemical transport models and multiple measurements. Early approaches (Fishman, 1978) before and during the Total Ozone Mapping Spectrometer (TOMS) studies combined LIMB (angled view to characterize stratosphere) and NADIR (downward view, characterizing total column) techniques to derive tropospheric ozone residuals. The 2004 launch of NASA's Aura mission with multiple ozone sensors is starting to produce more refined tropospheric ozone maps (e.g., Figure 15). However, delineating boundary layer ozone from free tropospheric reservoirs continues to pose significant interpretation challenges.

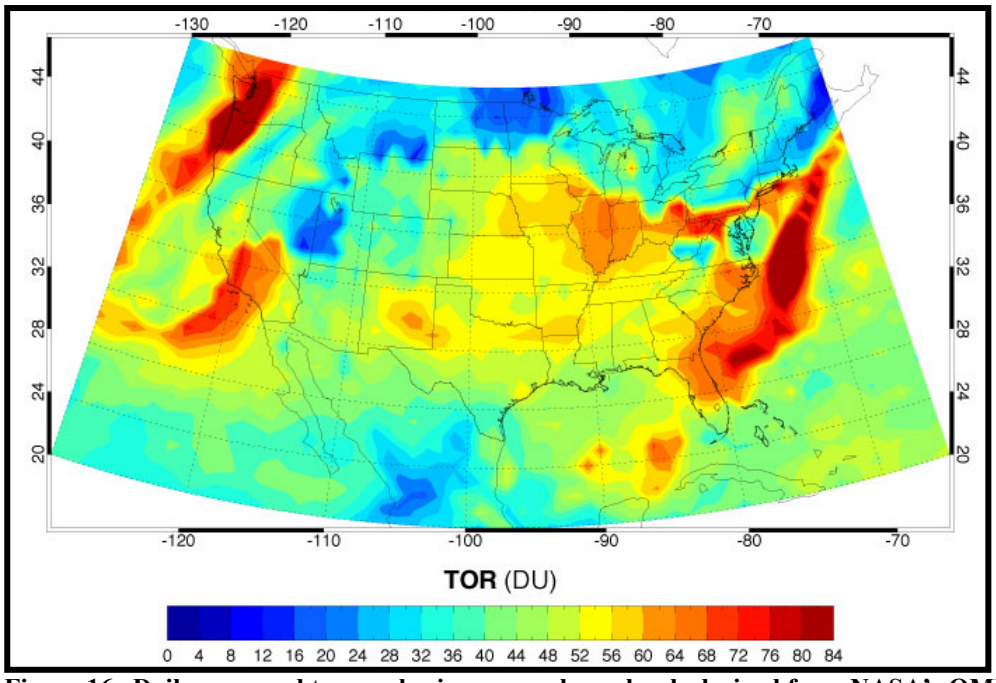

Figure 16. Daily averaged tropospheric ozone column levels derived from NASA's OMI in Dobson Units for June 22, 2005 (courtesy, J. Szykman, EPA and J. Fishman, NASA).

Measurement issues. Most satellite air quality observations are based on spectroscopic techniques typically using reflected solar radiation as a broad source of UV through IR electromagnetic radiation (LIDAR aboard CALIPSO does utilize an active laser as the radiation source). While the science of satellite based measurements of trace gases and aerosols is relatively mature, interferences related to surface reflections, cloud attenuation and overlapping spectra of nearby species require adequate filtering and accounting for in processing remote signals. For example, aerosol events episodes associated with clouds often are screened out in developing in applications involving AOD characterizations through MODIS. Correlations between AOD and surface aerosols generally are better in the Eastern U.S. relative to the West because due to excessive surface light scattering from relatively barren land surfaces.

Use of Satellite data in air quality management assessments. Satellite data, particularly fire and smoke plume observations and GOES meteorological data, support various air quality forecasting efforts servicing public health advisories. Forecasting is driven by characterizing the environment in current and immediate (1-3 days) future time frames. Air quality assessments require greater confidence in a systems (e.g., a model) response behavior to longer term, and usually much greater, changes in emissions, land use and meteorology; which requires greater confidence in formulation of numerous physical and chemical processes. Despite these differences, research and application products originally catalyzed by forecasting objectives generally overlap well with retrospective air quality assessment needs, the focus of this discussion.

Satellite products complement existing observational platforms and support the air quality assessment process through:

1. direct observational evidence of regional and long range intercontinental transport,
2. emission inventory improvements through inverse modeling,

3. evaluation of Air Quality Models,
4. tracking emissions trends (accountability), and
5. complementing surface networks through filling of spatial gaps.

As air quality assessments evolve toward embracing more pollutant categories, an attendant need to characterize a variety of spatial (and temporal) scales parallels places demands on developing more compositionally rich characterizations of air pollutants. Satellite technologies combined with partnerships with Federal agencies such as NASA and NOAA are assisting the air quality community by providing data that covers broad spatial regimes in areas lacking ground based monitors and, more importantly, a vertical compliment to our horizontal surface based networks. Although breathing zone monitoring is a rich data source, most pollutant mass resides beyond the representative reach of surface stations. During well mixed conditions with stable pressure systems during the afternoon, pollutant levels aloft often correlate well with surface conditions offering potential for "gap filling" in the surface based networks. Perhaps of greater utility is the use of satellite data to evaluate air quality models used to estimate air quality consequences of future emissions and climate scenarios. Satellite observations can be applied as a constraints on modeled total column mass or emission fields.

Satellites support hemispherical and global scale air quality assessments, which are projected to be of increasing importance to North American air quality as both the relative contribution of transported air pollution and air quality-climate interactions increases over the next few decades. The pattern of gradual lowering of air quality standards (Figure 16) also raises the importance of transported air pollution. The 2006 revision of the daily $PM_{2.5}$ NAAQS from 65 to 35 μg/m3 will increase the relative contribution of trans-oceanic dust transport to violations. Direct observational evidence of long distance transport clearly can be viewed with satellite imagery (Figures 17-18). Satellites often provide the only observation base for evaluating global scale air quality models in regions lacking adequate measurement and emissions inventory resources.

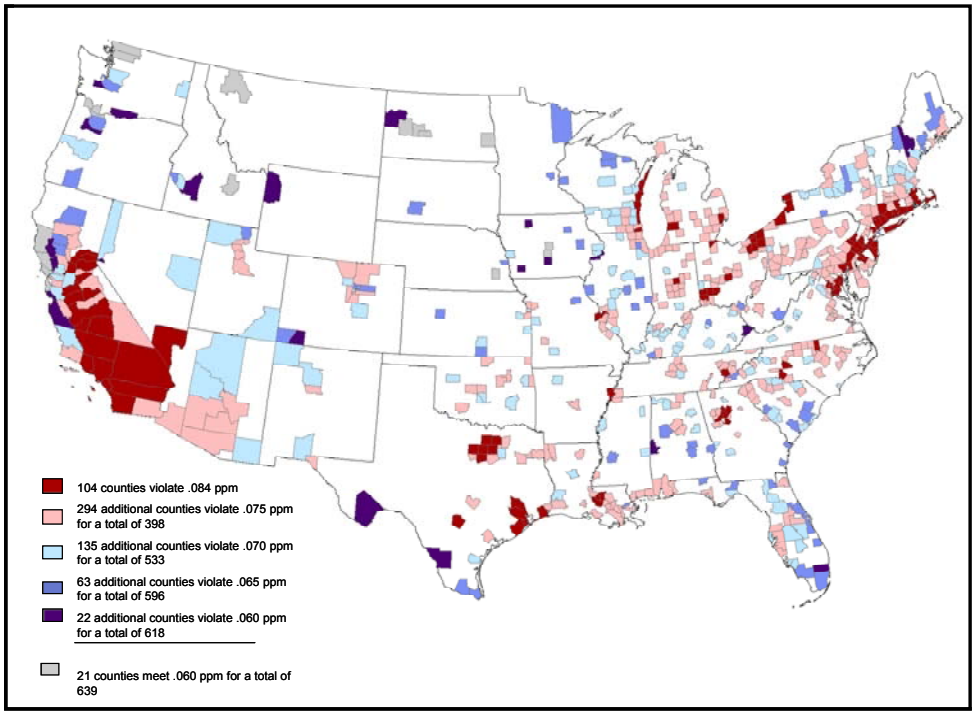

Figure 17. Escalating range of counties violating various levels of the ozone NAAQS, based on 2003-2005 observations.

Launched in 2004, NASA's Aura satellite mission (http://www.nasa.gov/mission_pages/aura/spacecraft/index.html) deploys sensors theoretically capable of measuring all criteria gases, methane, formaldehyde, nitric acid, nitrous oxide, water vapor, radicals (hydroxyl and hydroperoxy) and aerosols – a multiple pollutant space based complement to the NCore multiple pollutant ground based network and intensive field campaigns. NASA's Orbiting Carbon Observatory (OCO), scheduled to be launched in 2008, will be dedicated to tracking carbon dioxide levels which currently are captured on the Aqua based Atmospheric Infrared Sounder (AIRS) instrument. The Aqua, Terra, Aura and OCO all are part of NASA's Earth Observation System (EOS). Tropospheric column level ozone for the contiguous United States derived from the Ozone Monitoring Instrument (OMI, Figure 15) provides broad horizontal spatial coverage consistent with global (~ 100km) and regional scale (~ 30 km) Chemical Transport Models (CTM). When used in combination with CTMs, satellite column estimates can be used as an observation driven top-down check and modification through inverse modeling of emission inventories. Satellite data for CO, NO_2 and HCHO (Figure 19), as an indicator for biogenic isoprene, have been used for improving emission inventories (Fu et al., 2007; Martin et al., 2003, 2006; As longer term records are developed, satellite imagery offers another means of checking progress of major emission strategy plans as well as illustrating emissions growth in developing parts (East Asia) of the world (Figures 20 and 21).

An August, 2006 incursion of African dust transported across the Atlantic Ocean demonstrates the use of Satellite imagery capturing long range transport events (Figure 18). NASA's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) mission launched in

April, 2006 provides both column total and vertically resolved aerosol estimates using an active light source (LIDAR) to quantify light scattering. Resolving vertical gradients provides enhanced support for diagnosing CTM behavior and allows for screening of plumes reaching the surface in developing correlations between surface and satellite observations. CALIPSO builds on the ongoing success of the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA's Terra (EOS AM) and Aqua (EOS PM) satellites which has provided total aerosol column optical depths (AOD) for use in:

- Supporting development of wildfire and prescribed burning emission inventories (The 2005 NEI will include emissions from fires utilizing MODIS),
- Evaluating ability of air quality models such as CMAQ to characterize total column aerosol loadings, and
- Complimenting ground based PM2.5 monitors by filling in spatial gaps and adding intelligence to conceptualize our understanding of aerosol episodes (see http://idea.ssec.wisc.edu/).

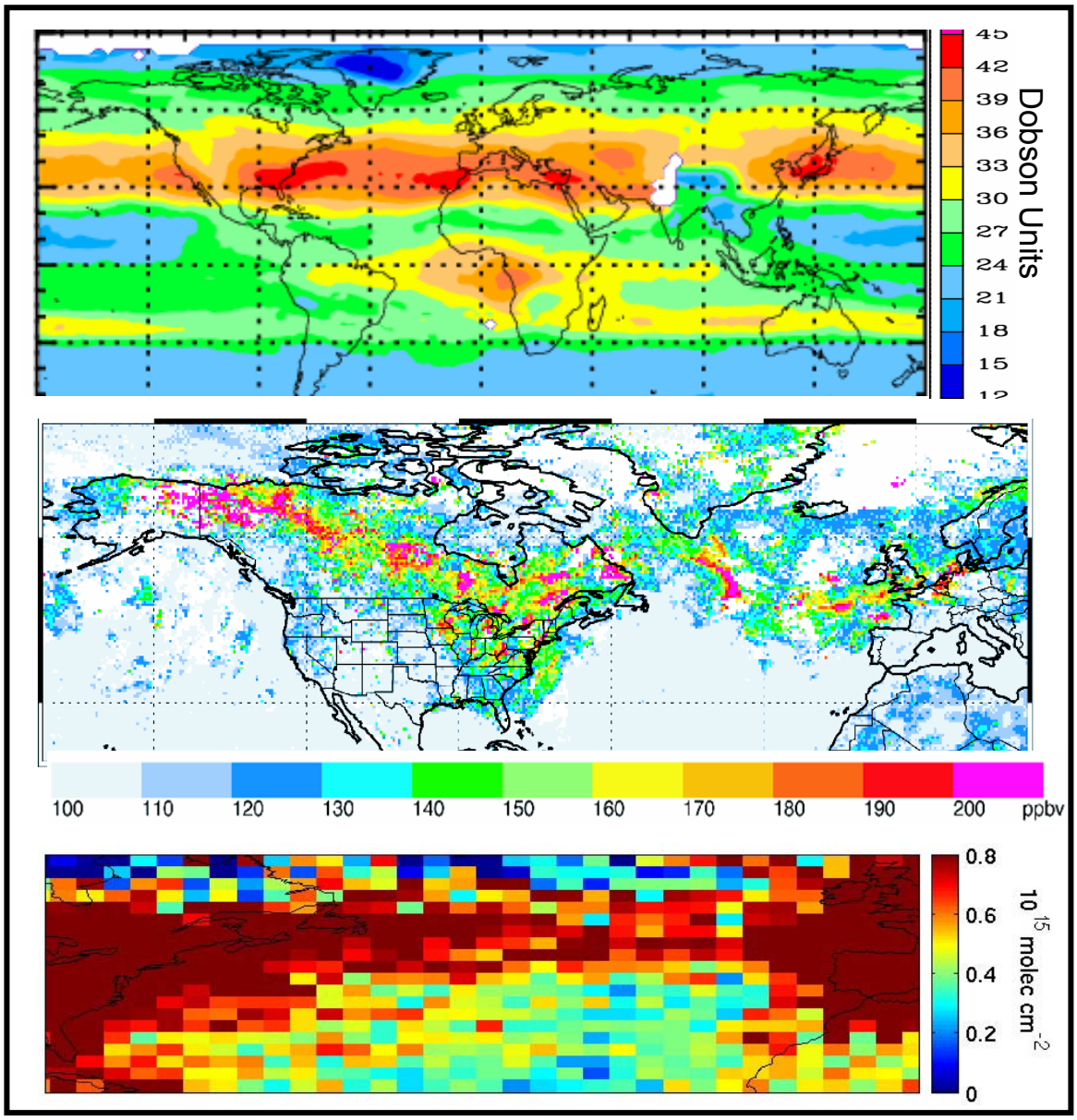

Figure 18. Panels capturing **t**rans-Atlantic transport: top (summer 1997 tropospheric ozone from GOME, Liu et al., 2006); middle (CO column totals from MOPITT for July 2004, Pfister et al., 2006**);** bottom (Tropospheric NO_2 from SCIAMACHY for summer 2004, Martin et al., 2006**).**

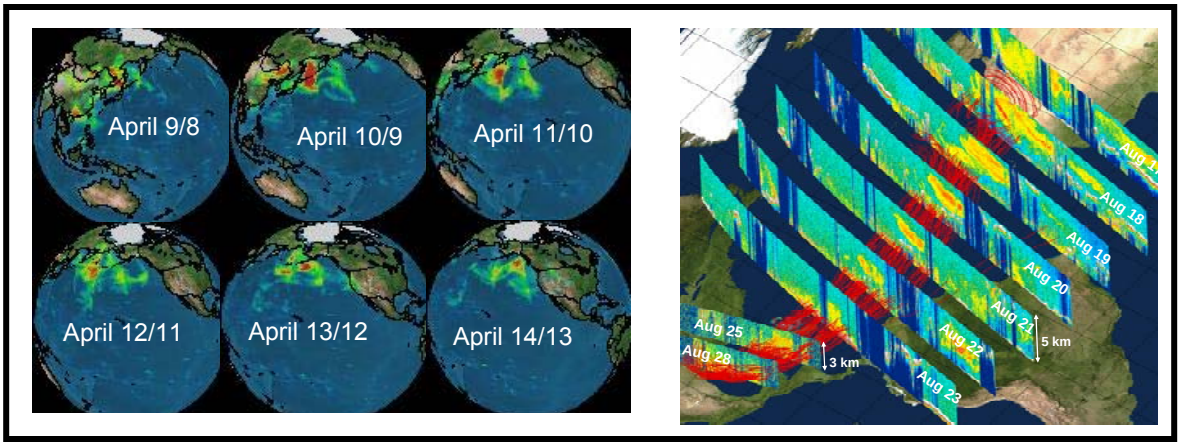

Figure 19. TOMS sequences of well characterized April, 2001Saharan Dust transport across Pacific (left), and CALIPSO sequences of August, 2006 African dust transport across the Atlantic Ocean (source, Winkler).

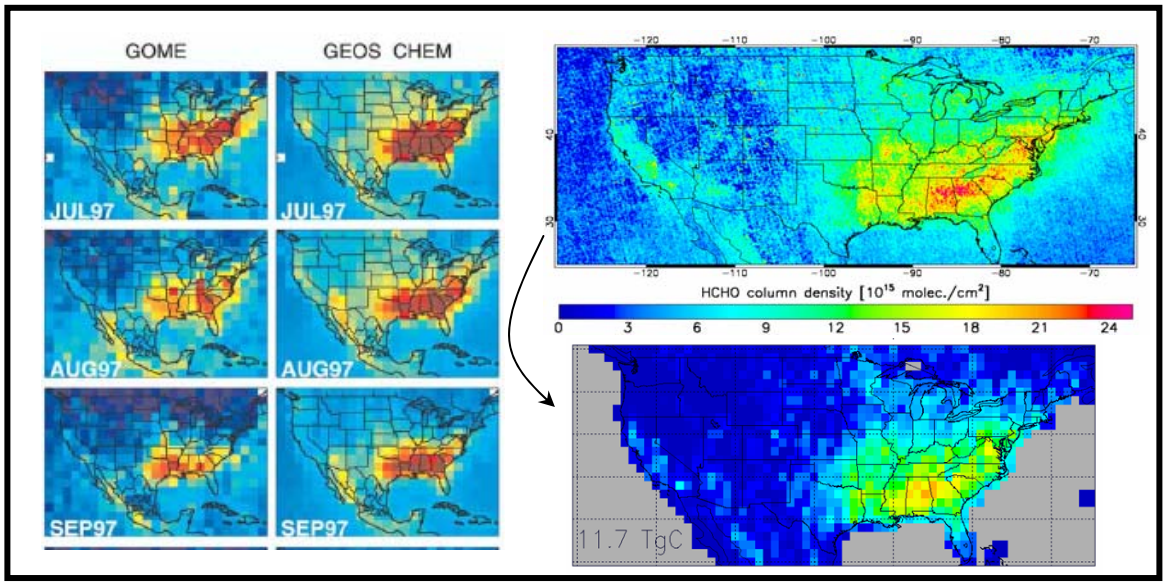

Figure 19. Left – Comparisons between GEOSchem global model and GOME derived formaldehyde fields (Abbott et al. 2003);Right – Summer 2006 OMI column HCHO and translation to isoprene emission estimates (Miller et al., 2007).

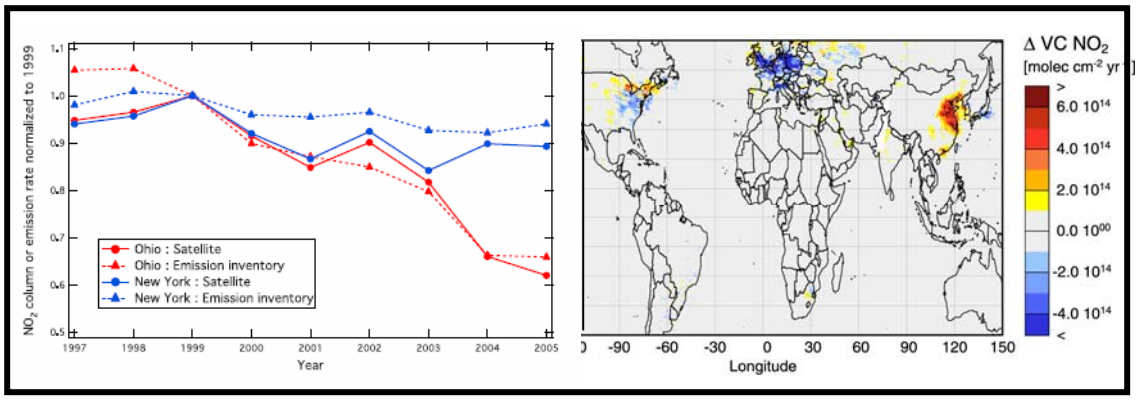

Figure 20. Left - superimposed Eastern U.S. emission and combined GOME and SCIAMACHY NO2 1997-2002 trends (Kim et al., 2006); right - GOME NO_2 trends from 1995 – 2002 (after Richter, 2005). Clear evidence of reductions in midwest U.S. and European NOx emissions, and increased NOx generated in Eastern Asia.

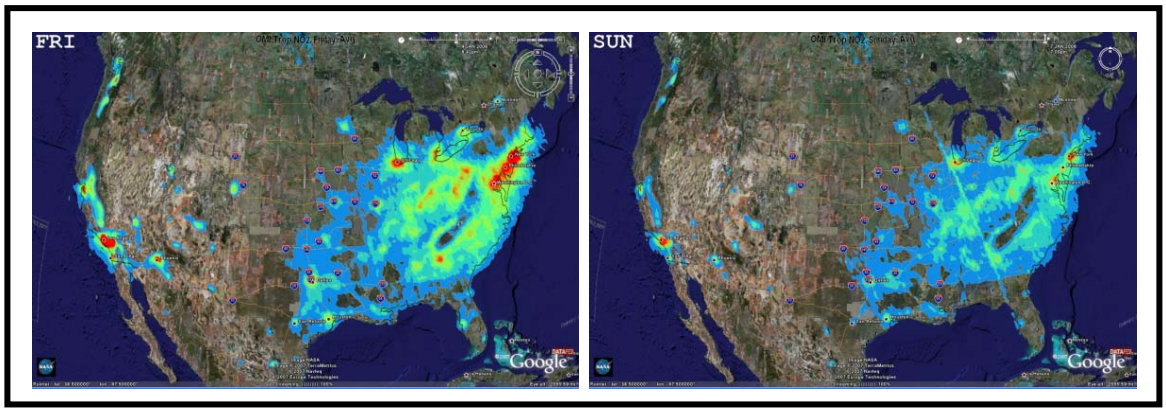

Figure 21. 2004 OMI NO_2 column images aggregated for all Fridays (left) and Sundays (right) indicating weekend/weekday patterns associated with reduced Sunday emissions (source, Husar).

TABLE 4. SATELLITE – BASED AIR QUALITY OBSERVING SYSTEMS[1,4]

Instrument	Satellite Platform[3]	Lead Federal Agency	Initiated	Measurement Parameters	Orbit & Horizontal Resolution	Location of Information and/or Data
OLS (Operational Linescan System)	DMSP satellites	DOD	1962?	Identify fires and smoke plumes	Polar Imagery only	http://www.af.mil/factsheets/factsheet.asp?fsID=94
BUV (Backscatter Ultraviolet Spectrometer)	Nimbus 4	NASA	1970-1980	O3, CO2, SO2	Sun synchronous	http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=1970-025A
SBUV (Solar Backscatter Ultraviolet Spectrometer)	Nimbus 7	NASA	1978-1993	O3, SO2	Polar	http://jwocky.gsfc.nasa.gov/n7toms/nimbus7tech.html
TOMS (Total Ozone Mapping Spectrometer)	Nimbus 7 Meteor 3 Earth-Probe	NASA	1978-1993 1991-1994 1996	O3, SO2, Aerosols	Polar ~100km	http://toms.gsfc.nasa.gov/fltmodel/spacecr.html
LIMS (Limb Infrared Monitor of the Stratosphere	Nimbus 7	NASA	1978-1979	O3, HNO3, NO2,	Polar	http://lims.gats-inc.com/about_lims.html
ATMOS (Atmospheric Trace Molecule Spectroscopy)	Spacelab 3 ATLAS -- 1,2,3	NASA	1985, 1992, 1993, 1994	O3, CFCl3, CF2Cl2, ClONO2, HCl, HF, CO, CH4, HCN, HNO3, NO, NO2, N2O, N2O5, Aerosols		http://remus.jpl.nasa.gov/atmos/sl3.html
CLAES (Cryogenic Limb Array Etalon Spectrometer)	UARS	NASA	1991-1993	O3, CFCl3, CF2Cl2 ClONO2, CH4, HNO3, NO, NO2, N2O, N2O5, Aerosols		http://umpgal.gsfc.nasa.gov/
HALOE (Halogen Occultation Experiment)	UARS	NASA	1991-2005	O3, HCl, HF, CH4, NO, NO2, Aerosols		http://umpgal.gsfc.nasa.gov/
ISAMS (Improved Stratospheric and Mesospheric Sounder)	UARS	NASA	1991-1992	O3, CO, CH4, NO2, N2O, N2O5, Aerosols		http://umpgal.gsfc.nasa.gov/
MLS (Microwave Limb Sounder)	UARS	NASA	1991-1999	O3, ClO, CH3CN, HNO3, SO2		http://umpgal.gsfc.nasa.gov/
GOES Imager (Geostationary Operational Environmental Satellites)	GOES-10 GOES-12	NOAA	1994	Fire products for WF_ABBA (imagery) and GASP (aerosol optical depth)	Geostationary	http://www.nesdis.noaa.gov/
GOES Sounder (Geostationary Operational Environmental Satellites)	GOES-10 GOES-12	NOAA	1994	Total column O3	Geostationary	http://cimss.ssec.wisc.edu/goes/goesmain.html#sndrinfo
AVHRR (Advanced Very High Resolution Radiometer)	NOAA-15 NOAA-16 NOAA-17[2]	NOAA	1998	Aerosol optical depth, particle size information and vegetation/drought index products related to air quality through fires	Polar 4km	http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html
SBUV/2 (Solar Backscattered Ultraviolet Radiometer Model 2)	NOAA-16 NOAA-17[2]	NOAA	2000	Total and profile O3 from surface to top of atmosphere in ~5 km thick Umkehr layers	Polar	http://www2.ncdc.noaa.gov/docs/podug/html/c4/sec4-4.htm

TABLE 6. SATELLITE – BASED AIR QUALITY OBSERVING SYSTEMS[1,4] (continued)

MOPITT (Measurement of Pollution in the Troposphere)	EOS Terra	NASA	1999	CO, CH4	Polar 22 x 22 km^2	http://www.eos.ucar.edu/mopitt/
MISR (Multi-angle Imaging SpectroRadiomenter)	EOS Terra	NASA	1999	Aerosol properties and plume height information near the vicinity of fires	Polar ~1km	http://www-misr.jpl.nasa.gov/mission/introduction/welcome.html
MODIS (Moderate Resolution Imaging Spectroradiometer)	EOS Terra EOS Aqua	NASA	1999 2002	O3, Aerosol optical depth, particle size information, fine particle fraction, and forest fires	Polar 1km	http://modarch.gsfc.nasa.gov/index.php
AIRS (Atmospheric Infrared Sounder)	EOS Aqua	NASA	2002	Total column ozone, surface temperature, temperature and moisture vertical profiles, (plus under development are CO and CO2 total column, O3 vertical distribution, and CH4 distribution)	Polar 50km	http://www-airs.jpl.nasa.gov/
HIRDLS (High Resolution Dynamics Limb Sounder)	EOS Aura	NASA	2004	O3, CFCl3, CF2Cl2, ClONO2, CH4, HNO3, NO2, N2O, N2O5, Aerosols	Polar	http://aura.gsfc.nasa.gov/index.html
MLS (Microwave Limb Sounder)	EOS Aura	NASA	2004	O3, BrO, ClO, HOCl, HCl, CO, HCN, CH3CN, HNO3, N2O, OH, HO2, SO2	Polar	http://aura.gsfc.nasa.gov/index.html
OMI (Ozone Monitoring Instrument)	EOS Aura	NASA	2004	O3, BrO, OClO, HCHO, NO2, SO2 and aerosol	Polar 12 x 24 km^2	http://aura.gsfc.nasa.gov/index.html
TES (Total Emission Spectrometer)	EOS Aura	NASA	2004	O3, NOy, CO, SO2, CH4	Polar 26 x 42 km^2	http://aura.gsfc.nasa.gov/index.html
CALIPSO (Cloud-Aerosol Lidar & Infrared Pathfinder Satellite Observations)	CALIPSO	NASA	2005	Aerosol optical depth, backscatter, extinction	Polar 0.3 x 0.3 km^2	http://www-calipso.larc.nasa.gov/about/
OMPS (Ozone Mapping and Profiling Suite)	NPOESS - Preparatory Project	NOAA	2006	Total column and vertical profile ozone data	Polar	http://www.ipo.noaa.gov/Projects/npp.html
VIIRS (Visible Infrared Imaging Radiometer Suite)	NPOESS - Preparatory Project	NOAA	2006	Aerosol optical depth	Polar	http://www.ipo.noaa.gov/Projects/npp.html
Orbiting Carbon Observatory	OCO	NASA	2008	CO2	Polar	http://oco.jpl.nasa.gov/
APS & TIM (Aerosol Polarimetry Sensor & Total Irradiance Monitor)	Glory	NASA	2008	Black carbon soot, other aerosols, total solar irradiance, cloud images	Sun-synchronous, circular, Low Earth Orbit	http://glory.gsfc.nasa.gov/

Footnotes:

1. Non-U.S. satellite systems are not included in table at this time.

2. As of 3/15/06 the operational satellite platforms may need to include NOAA-18.

3. CALIPSO -- Cloud-Aerosol Lidar & Infrared Pathfinder Satellite Observations
   DMSP -- Defense Meteorological Satellite Program
   EOS -- Earth Observing System
   GOES -- Geostationary Operational Environmental Satellites
   NOAA -- National Oceanic and Atmospheric Administration
   NPOESS -- National Polar-orbiting Operational Environmental Satellite System
   OCO -- Orbiting Carbon Observatory
   UARS -- Upper Atmosphere Research Satellite

4. See the following table for additional information on NASA satellites, instrument systems, pollutants measured, and data availability:

Table 6, cont.
Key Atmospheric Chemistry & Dynamics Data Sets at the NASA Goddard DAAC

Missions	Nimbus 4	Nimbus 7	Nimbus 7 Meteor 3 ADEOS 1 arth-Probe	Nimbus 7	Spacelab 3, ATLAS 1,2,3	UARS				ERS-2	Terra Aqua	Aqua	Aura			
Instruments	**BUV**	**SBUV**	**TOMS**	**LIMS**	**ATMOS**	**CLAES**	**HALOE**	**ISAMS**	**MLS**	**GOME**	**MODIS**	**AIRS**	**OMI**	**HIRDLS**	**MLS**	**TES***
Data Period	Apr '70-May '77	Nov '78-May '93	Nov '78-Present	Oct '78-May '79	'85, '92, '93, '94	Oct '91-May '93	Oct '91-Present	Sep '91-Jul '92	Sep '91-Jul '99	April '95-Present	Mar '00-Present	Sep'02-Present	Jul'04-Present	Jul'04-Present	Jul'04-Present	Jul'04-Present
Spectral Region	255 - 380 nm	255 - 340 nm	309 - 360 312 - 380 nm	6.2 - 15 µm	2.98 - 15 µm	3.5 -12.7 µm	2.43 -10.25 µm	4.6 -16.6 µm	63, 183, 20 GHz	240 - 790 nm	0.4 -14 µm	0.4 -1.1, 3.74 -15.4 µm	270 - 500 nm	6.12 -17.76 µm	118, 190, 240, 640 GHz, 2.5 THz	3.2 -15.4 µm
Bands	13	13	6	6	16	9	8	8	3	3072	36	2382	1560	22	5	12
O_3	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
BrO										•			•		•	
$CFCl_3$					•	•								•		
CF_2Cl_2					•	•								•		
ClO									•						•	
OClO										•			•			
$ClONO_2$					•	•								•		
HOCl															•	
HCl					•		•								•	
HF					•		•									
HCHO										•			•			
CO					•			•				•			•	•
CH_4					•	•	•	•				•		•		•
CH_3CN									•							
HCN					•										•	
HNO_3				•	•	•			•					•	•	•
NO					•	•	•									
NO_2				•	•	•	•	•		•			•	•		•
N_2O					•	•		•						•	•	
N_2O_5					•	•		•						•		
OH															•	
HO_2															•	
H_2O / Humidity				•	•	•	•	•	•	•	•	•		•	•	•
SO_2	•	•	•						•	•			•		•	
Aerosols			•		•	•	•	•			•		•	•		
Cloud	•	•	•								•	•	•	•		
Temperature				•		•	•	•	•		•	•		•	•	•
Geopotential Height				•					•			•		•	•	
Reflectance	•	•	•								•	•	•			

Please note that the table above does not contain parameters from all sensors and products. Also available from the GES DAAC are many more Atmospheric and Earth Sciences data products from AIRS, AMSU-A, HSB, MODIS, SeaWiFS, OCTS, CZCS, TRMM (PR, TMI, VIRS), TOVS Pathfinder, Data Assimilation Model (GEOS-1, GEOS-DAS, CPC/ACDB), UARS (HRDI, WINDII, SOLSTICE, SUSIM, PEM), SORCE, several Field Campaigns, and Interdisciplinary data sets consisting of 70 geophysical Earth Sciences parameters. TOMS & SBUV reprocessed data (version-8) are now available on DVD-ROM. The MLS and OMI-Aura products & Visualization tools are now available from GES DISC.

* Data from the Aura instrument 'TES' is archived at the NASA Langley Atmospheric Sciences Data Center (http://eosweb.larc.nasa.gov/).

http://disc.gsfc.nasa. help@disc.gsfc.nasa.go

Section 2.1.8: Surface Water and Soil/Sediment Measurement Programs

Measurement programs for streams, lakes, estuaries, soils and sediments generally lack the sustained funding and routine, widely deployed sampling attendant with air monitoring programs. EPA's Environmental Mapping and Assessment Program (EMAP, http://www.epa.gov/emap/) and related STORET (http://www.epa.gov/storet/) data base system provide a broad research based organizing structure for a variety of aquatic and terrestrial sampling and measurement programs (physical, chemical and biological indicators) across the United States. While these structures enable access to a wealth of archived and ongoing research studies, most of the information reflect area specific campaigns with discrete sampling periods. Consequently, trends analyses over several years or decades that link air program implementation strategies through atmospheric networks to aquatic and terrestrial systems are a noted information gap for supporting accountability assessments. The following brief overviews do not address the measurement programs associated with drinking water quality or swimming advisories which are conducted under the auspices of local municipalities (e.g., public health agencies and drinking water authorities) with a diversity in protocols and data access routes that compromise the utility of such data for accountability and multiple media linkage assessments.

Routine surface water monitoring programs. The Temporally Integrated Monitoring of ecosystems (TIME) project (Stoddard, 1990) was developed in the early 1990's to track progress of Eastern United States lakes and streams (Figure 22) in response to the CAAA Title 4 reductions in sulfur and nitrogen oxides. Most key water column inorganic ions are measured to characterize changes in acid neutralizing capacity (ANC), hydrogen ion, dissolved inorganic (DIC) and organic carbon (DOC). A subset of TIME sites is incorporated in the Long-Term Monitoring (LTM) project (Ford et al. 1993, Stoddard et al. 1998b), providing observations back to the early 1980's. Sustainability of much of the TIME/LTM efforts has been due to private-public partnerships among Federal and State agencies and the utility industry coordinated through the Adirondack Lake Survey Corporation (http://www.adirondacklakessurvey.org/). Comparable routine surface water measurement programs for Western United States and Mexico are not available, although a number of surveys targeted for U.S. National Parks have been conducted (EPA, 2007).

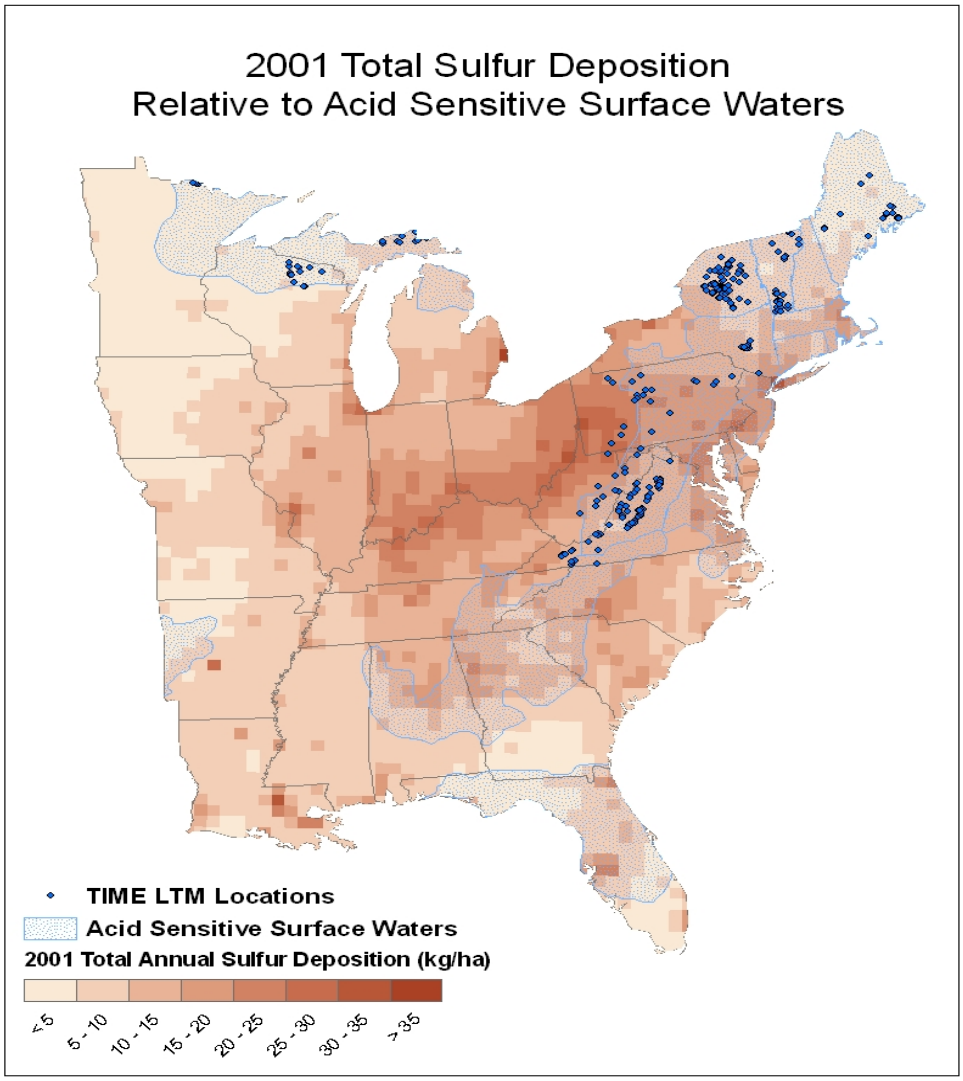

Figure 20. Location of Time/LTM sites overlaid with annual sulfur deposition fields based on CASTNET and NADP measurements and CMAQ results (courtesy, R Haeuber)**.**

Terrestrial indicators. The Forest Inventory and Analysis (FIA) National Program (http://fia.fs.fed.us/tools-data/) under the United States Forest Service maintains a routinely upgraded data base covering a variety of forest health metrics across the united States. The FIA focuses on the general status of forest types and areal coverage using a combination of remote sensing data and onsite surveys. Forest Health Monitoring (FHM) plots are a subset of the FIA program that includes more detailed, site specific measurements, including soil chemistry, lichen surveys (relative to trees, lichens generally are more responsive to environmental stresses) and ozone related vegetation injuries.

[follow up: NSF's National Ecology Observation Network (NEON) and Smithsonian Institution Global Earth Observatories (SIGEO) long term eco tract studies]

Section 2.1.7 European Air Monitoring Networks

Extensive air monitoring networks have also been implemented in Europe. In addition to the SVOC programs discussed earlier, many European based programs are served by centralized organization structures linked to international efforts such as Convention on Long Range Transport of Air Pollution (LRTAP, http://www.unece.org/env/lrtap/) and the underlying technical assessment body, Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP). The Global Atmospheric Watch (GAW) program (http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html) under the World Meteorological Organization (WMO) provides quality assurance guidelines and data access to an important body of air quality measurements relevant to assessing intercontinental pollution transport and climate forcing phenomena. The Norwegian Institute for Air Research (NILU, http://www.nilu.no/index.cfm?ac=topics&folder_id=4572&lan_id=3), maintains a data base for much of the European based networks. These programs are noted not only as resources for large spatial scale environmental assessments, but also as examples of coordination and data harmonization that could be extended or replicated for North American purposes. The MOZAIC and CARIBE routine aircraft atmospheric chemistry vertical profile measurements illustrate the close linkage between European observation systems and air quality modeling and process formulation studies. European based efforts in deposition monitoring relevant to sensitive ecosystems preceded efforts in North America and continue to lead the International community in coordinated efforts in sustaining science based measurement programs.

Several hundred sites are indicated in Table 7 which includes combined contributions from all countries ranging from a few sites to tens of sites per country. Measurements for a variety of air pollutants are addressed including O3, heavy metals, POPs, particulate matter, VOCs, and deposition from acidifying / eutrophying compounds. Monitoring programs extend back to the 1970s.

TABLE 7. International and European Air Monitoring Programs

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
EMEP -- Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (encompasses networks for ~37 European countries and organizations)	UNECE	270	1977	**Acidifying / Eutrophying Compounds** (precipitation): SO4, NO3, NH4, trace elements, pH, acidity (air): SO2, NO2, HNO3, NH3, PM10, PM2.5, major ions **O3** **Heavy Metals** precipitation, major ions, PM2.5, PM10, Hg, wet deposition **POPs** precipitation, air, deposition **Particulate Matter** PM2.5, PM10, EC, OC, TC, BC **VOC** Hydrocarbons, Carbonyls	http://www.nilu.no/projects/ccc/emepdata.html
EUROTRAC -- The European Experiment on the Transport and Transformation of Environmentally Relevant Trace Constituents over Europe	International Executive Committee (European Countries)	???	1986	EUROTRAC programs performed analyses utilizing data from existing or specially designed monitoring networks in order to: 1. elucidate the chemistry and transport of ozone and other photo-oxidants in the troposphere, e.g., TOR -- 30 O3 stations and ALPTRAC -- 15 snow monitoring sites 2. identify processes leading to the formation of acidity in the atmosphere, particularly those involving aerosols and clouds. 3. understand uptake and release of atmospheric trace substances by the biosphere.	http://www.gsf.de/eurotrac/index_what_is.html
EUROTRAC-2 -- The EUREKA project on the transport and chemical transformation of trace constituents in the troposphere over Europe; second phase. Subprojects: – AEROSOL – BIATEX-2 – CAPMAN – CMD – EXPORT-E2 – GENEMIS – GLOREAM – LOOP – MEPOP – PROCLOUD – SATURN – TOR-2 – TRAP45 – TROPOSAT	International Scientific Secretariat (European Countries and EU)	???	1996	EUROTRAC-2 programs performed analyses utilizing data from existing monitoring networks in order to: support the further development of abatement strategies within Europe by providing an improved scientific basis for the quantification of source-receptor relationships for photo-oxidants and acidifying substances.	http://www.gsf.de/eurotrac/index_what_is.html

3.0 Measurement Gaps to Support Integrated Assessments.

The previous section provided an inventory of observation systems which is the underlying framework for integrated environmental assessments addressing multiple- pollutant and media-interactions within an accountability framework. This section addresses the relative strengths and weaknesses of observational programs with recommendations that potentially foster improved network linkage.

Network design is driven by the specific needs of an associated sponsoring organization and priorities are not high for observations addressing broadly integrated air management assessments. Consequently, a comprehensive multiple organization view of observational systems is necessary to take advantage of existing network integration elements and identify important information gaps that may strengthen the interoperability of networks. Because observations can serve multiple objectives, and disparate organizations share the common need of characterizing the environment, an intrinsic connectivity exists among a variety of measurement programs. Integration opportunities can be viewed from a number of perspectives, including:

- Linking similar pollutants horizontally by blending urban and rural based networks (e.g., urban based speciation networks with rural based IMPROVE program; SLAMs ozone urban stations complementing CASTNET rural ozone stations);
- Assimilating pollutants vertically through the atmosphere by blending of satellite data, ground surface measurements and vertically resolved systems to yield some combination of total integrated column values, vertically resolved gradients and improved surface level resolution through correlation relationships between surface and column based observations;
- Combining precipitation and ambient/dry observation networks to develop deposition fields, as performed currently through the CASTNET and NADP programs;
- Aligning atmospheric deposition observations with soil and surface water measurement campaigns;
- Collocating a variety of different species measurements to yield multiple pollutant characterizations within a consistent spatial frame (e.g., NCore level 2 sites); and
- Matching ambient observation measurement fields with human activity patterns to estimate exposures.

3.1 **Multiple Pollutant Coverage**.

Routine ground based networks operated by States, local agencies and Tribes incorporate a mix of single and multiple pollutant measurement stations designed around a criteria pollutant of interest. Agencies often increase efficiency of network operations deploying multiple sensor packages resulting in reduced travel and maintenance expenses. More recent network deployments starting with PAMS and extending through the PM speciation, air toxics trends and NCore programs show increasing evolution toward measurement collocation. Networks not driven by specific regulatory requirements (SEARCH, CASTNET/NADP, IMPROVE) often incorporate multiple measurements at each site. Time integrated field samples (e.g.,

filters and gas canisters) delivered to laboratories benefit from having access to a variety of analysis procedures. In-Situ chromatography (typical PAMS arrangement for VOCs) and remote sensing spectroscopy used in satellites are capable of separating signals from a variety of compounds. Consequently, an abundance of collocated multiple pollutant measurements is available.

Why are collocated measurements necessary to support an integrated assessments? Collocated measurements add diagnostic value to virtually any assessment of interest. From an air quality model evaluation perspective, a multiple pollutant observation base is critical in constraining a model's flexibility to minimize adjustment of inputs and parameterizations, to minimize compensating effects and better guide model improvement and behavior process. Similarly, availability of multiple measurements across a variety of airsheds and populations increases the statistical power to better enable the development of associations between health effects and air pollution attributable to either a single pollutant or groupings of pollutants. These examples can be extended to applications addressing emission inventory improvement, weight of evidence arguments and general development of conceptual models establishing the technical context preceding development of air quality assessments.

The NCore multiple pollutant network will add 75 multiple pollutant gas and aerosol measurement sites across the United States, which benefit from existing PM speciation infrastructure. While this modest addition of sites will provide some direct diagnostic and central site value, it is expected that the program will catalyze future growth of multiple pollutant sites.

3.1.1 Inhalable Hazardous Air Pollutants.

What measurement species are recommended to increase multiple pollutant richness of our networks? A relative scarcity of hazardous air pollutant (HAPs) measurements compromises assessments directed explicitly toward air toxics or more broadly in a multiple pollutant context. Extensive monitoring coverage of all 188 listed HAPs is not practical in a resource limited environment. Numerous State, local agency and private laboratories perform air toxics analyses, raising concerns regarding standardization of protocols and data intercomparability across agencies. The problem is compounded by typically low concentration values approaching and often below instrument detection limits. In addition, protocol development issues still exist for important compounds such as acrolein and hexavalent chromium.

Among the highly ranked 33 air toxics species, benzene observations are fairly widespread and relatively reliable. During the initial start-up of the NATTS, six priority HAPs (formaldehyde, benzene, 1,3 butadiene, hexavalent chromium, acrolein and arsenic) were targeted for inclusion based on results of the 1996 National Air Toxics Assessment (http://www.epa.gov/ttn/atw/nata/). EPA expanded this list to include:

> Acrolein, Perchloroethylene, Benzene, Carbon tetrachloride , Chloroform, Trichloroethylene, 1,3-butadiene, 1,2-dichloropropane, Dichloromethane, Tetrachloroethylene, Vinyl chloride, Formaldehyde, Acetaldehyde. Nickel compounds (PM10), Arsenic compounds (PM10), Cadmium compounds (PM10), Manganese compounds (PM10), Beryllium (PM10), Lead (PM10), Hexavalent chromium (TSP), Benzo(a)pyrene.

Based on efficiencies in methodologies and recent National Air Toxics Assessment (NATA- http://www.epa.gov/ttn/atw/nata1999/) results. Carbonyl measurements (acetaldehyde and formaldehyde) from PAMS have provided additional spatial coverage relative to other HAPs, although cartridge sampling techniques are relatively labor intensive. The PM speciation program does analyzes for a variety of metals, but the 2.5 micron particle size cut which does not account for total inhalable metals concentrations.

Beyond a number of analytical complexities, air toxics provide significant challenges associated with the wide variety of species often associated with a local scale or unique source specificity. Given the uniqueness of specific HAPs, a flexible measurement strategy adoptable to the location and pollutant of interest is required in addition to the modest national design of the NATTS, which is analogous to ozone and fine particles which exhibit similar characteristics across broad spatial domains. The routinely measured HAPs are incorporated in the relatively sparse 22 site NATTS network, recognizing the need to allocate resources for locally designed efforts. Since 2005, the EPA has awarded annual air toxics community monitoring grants intended to address the local scale nature of air toxics exposures.

3.1.2 Mercury

Increased attention on mercury lead to both the Clean Air Interstate (CAIR, http://www.epa.gov/interstateairquality/) and Clean Air Mercury Rules (CAMR – http://www.epa.gov/camr/) requiring significant reductions of mercury from major electrical generating units (EGUs) in the Eastern United States over the next two. Mercury poses interesting multiple spatial scale assessment challenges given the importance of global cycling and near source fate and transformation processes in determining deposition patterns. Since digestion of fish is a major delivery path, linkage between atmospheric and terrestrial and aquatic systems challenges multiple media assessment capabilities.

Combined with uncertainties in mercury chemistry parameterization schemes, a sustained network of speciated dry mercury measurements is particularly important for tracking progress in CAIR and CAMR and improving mercury assessment capabilities. Dry mercury measurements that compliment the existing precipitation based Mercury Deposition Network (MDN) are critical information pieces that would add value to understanding important atmospheric transformations that impact deposition patterns, and enable some reasonable mass balance accounting supporting model evaluation and accountability assessments. A variety of research campaigns over the last decade have lead to an informal collection of sites providing insight into source-receptor phenomena and deposition behavior, as well as advances in monitoring technology which remains labor intensive and is considered relatively expensive and complex. A gradual expansion of the pilot dry mercury network coordinated through the NADP is encouraged.

3.2 Spatial and temporal scale considerations

Air Pollution assessments are influenced by a variety of spatial (and temporal) scales. Typically, monitoring resources are applied to a specific scale of interest such as a near roadway exposure or long range transport assessment. Interactions across multiple scales and attennant observation gaps also should be considered. For example, separation of the urban area contribution to aerosol loading requires knowledge of the regional burden. Similar reasoning applies to contributions of long range transport to regional and urban settings, as well as considering the reverse contributions from smaller to larger scales. Important spatial and temporal gaps in measurement networks include:

- Surface background and rural locations,
- Enhanced time resolved surface aerosol speciation measurements,
- Time resolved integrated column measurements from satellites, and
- Vertically resolved gradients of chemical species.

Spatial scales (horizontal). Early impressions of air pollution often were based on visible plumes associated with sight lines corresponding to urban and near source spatial scales. In contrast, characterization of stratospheric ozone, climate modifications and transport and cycling of POPs are viewed as global issues. Perception of tropospheric ozone pollution transitioned from an urban scale view evolving toward a regional concern through the late 1980s-1990s and now is recognized as multiple scale problem influenced by global scale accumulation and precursor transport processes (Figure 1). Consideration of global scale ozone processes is of increasing importance given:

- declining ozone concentration patterns in North America,
- observational evidence of rising background ozone levels and long distance transport of ozone and precursors,
- increasing ozone precursor emissions from expanding economies beyond North America; and,
- gradual lowering of North American ozone standards.

Throughout the 1970's and 1980s, the TSP and PM_{10} particulate matter standards largely were viewed as near source, local scale problems. The 1997 adoption of the $PM_{2.5}$ annual standard recognized a strong regional aerosol component associated with secondary formation and transport. The 2006 revision of the daily $PM_{2.5}$ standard to 35$\mu g/m^3$ (from 65) should simultaneously elevate the importance of local generation and long range transport processes. Local or near source impacts will contribute proportionally more and result in more exceedances of the daily standard, especially considering a gradual reduction in regional aerosol levels associated with national strategies targeting PM precursor gases. And, transport of aerosols from distant wildfires and Asian and African dust could increase exceedances of the daily standard. As noted earlier, several inhalable HAPs tend to be viewed primarily as near source issues while persistent HAPs are subject to global and multiple (e.g., Hg) scale influences.

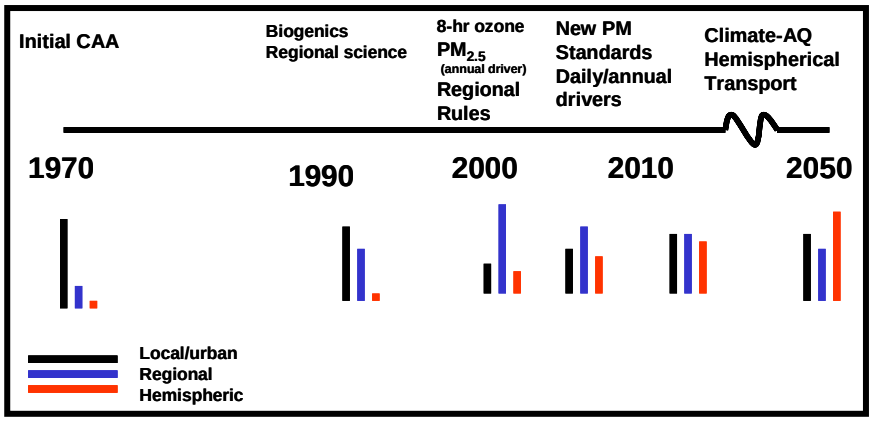

Figure 21. Evolutional change in significance of spatial scales in National Air Pollution Management practice.

Associating certain pollutants along spatial scales (Figure 2) tends to neglect influences between scales which generally is bi-directional, but typically treated in a single (large to small) scale direction (e.g, fixed boundary conditions driving air quality modeling simulations). Rarely are local scale processes accounted for in large scale applications; and almost never are bi-directional influences across scales (or environmental media) accommodated in assessment practices. Efficiencies gained from using uni-direction or single scale treatments generally are justified considering, for example, that hemispheric transport only minimally impacts a near roadway assessment. However, the trend toward more comprehensive environmental assessments carries an increasing importance of spatial scale interactions resulting in emerging geometries in model development that should be attended by a parallel evolution of linking observational scales.

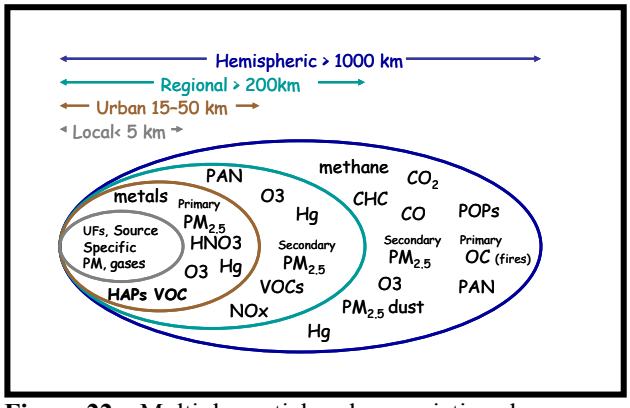

Figure 22. Multiple spatial scale associations by pollutant category.

Important gaps in surface networks. Examples where steps to integrate networks to improve spatial coverage include CASTNET and SLAMs and IMPROVE and EPA STN rural and urban network pairs for surface ozone and aerosol speciation, respectively. Adoption of relatively minor adjustments in quality assurance protocols will increase broader integrated analysis of the ozone networks. EPA is replacing urban based STN carbon aerosol measurement and analysis protocols with those used in the rural based IMPROVE network to increase data

harmonization. Despite these modifications, rural coverage of most gaseous species is not adequate for model evaluation needs and assessments designed to address ecological effects.

Some noted information gaps in surface based networks include:

Absence of VOC measurements in representative areas.

Over the last two decades the importance of biogenically generated VOCs (isoprene, terpenes, sesquiterpenes) has been recognized in the formation of ozone and secondarily formed $PM_{2.5}$. Nevertheless, the urban based PAMS network designed in the early 1990s remains the primary source of VOC data in the United States. Additional coverage in for U.S. cities is provided by the 22 NATTS air toxics sites. The design of the current VOC networks does allow for associateing reasonable urban based VOC air quality and emissions trends, an initial step in accountability analyses. However, the absence of VOC data in most moderate sized cities raises concerns regarding the overall representativeness of a network based primarily on the severity of ozone problems in the early 1990s. More troubling is the lack of rural based VOC data, especially formaldehyde which, in addition to being a designated HAP, can provide relational insight into biogenic emissions. Formaldehyde is well enmeshed in atmospheric chemistry pathways thereby providing a useful diagnostic for model evaluations. In addition, formaldehyde could indicate alterations in atmospheric chemistry associated with potential transition to alternative transportation fuels (e.g., grain based and natural gas). Finally, the value of total column formaldehyde from satellites could be enhanced by providing a more spatially rich surface observation complement

Consideration also should be given to adding surface based glyoxal measurements in representative locations. Glyoxal is formed from the oxidation of various urban based VOCs and can be thought of as an analog to reactive nitrogen (NOy), serving as a relatively well conserved species reflecting fate and transformation of VOCs. Recent studies (Carlton et al. ???) suggest glyoxal participates in heterogeneous cloud and fog based reactions yielding carbonaceous aerosols. Successful ground based glyoxal measurements using differential optical absorption spectroscopy (DOAS) have been demonstrated in Mexico City (Volkamer et al., 2005). Total column glyoxal also is provided by satellites and, in combination with formaldehyde, ground based observations enable evaluation of satellite products (Wittrock et al., 2007).

Nitrogen species.

Environmental assessments relevant to ozone, aerosols, acidification, eutrophication and visibility rely on characterization of atmospheric nitrogen. Unfortunately, there are numerous nitrogen observation gaps which is a concern considering that NOx emission reductions have dominated national air program rules over the last decade. An adequate observation base does not exist to determine if ambient nitrogen response is consistent with measured and predicted NOx emissions changes. The ability of the existing urban oriented NOx measurement network to detect ambient NOx changes associated with regional scale EGU emission reductions is compromised by strong local mobile source NOx emission signals. Also, NO_2 data from most network NOx monitors remains compromised by other oxidized nitrogen

species, an issue prevalent for nearly two decades. The NCore network will provide a modest contribution by providing for reactive nitrogen (NOy) measurements in over 20 rural locations and, ideally, spur greater coverage and deployment of instruments producing true NO_2 observations. True NO_2 is a useful diagnostic species for atmospheric chemistry processes (Figure 3) and serves as a surface based link to satellite NO_2 column data. Further resolution of reactive species including peroxy acetyl nitrate (PAN) and nitric acid (HNO3) would elevate our ability to diagnose a number of processes related to deposition and ozone production along transport corridors. An expected increased penetration of grain based fuels potentially would elevate PAN concentrations, and along with other carbonyl observations PAN would provide a useful accountability indicator relating the impact of new fuels on ambient chemistry.

Reduced nitrogen species, ammonia gas and ammonium ion, are important components of an overall nitrogen mass balance and important components relevant to visibility, fine particles and ecosystem deposition assessments. There is a scarcity of ambient ammonia measurements as most ammonia measurement programs are located in strong source agricultural locations to estimate emissions flux. Ammonium ion is analyzed as part of the chemical speciation program, but ammonia volatization within the sampler and during filter handling creates a negative bias in those values. Routine measurements at one or two representative locations of nitrate radical (NO_3^-), the dominant nighttime oxidation specie, also would enable diagnosing model behavior relative to overall nitrogen balances as well as secondary aerosol formation. Successful ground based measurements using differential optical absorption spectroscopy (DOAS) have been demonstrated for the past 20+ years, including year-round sampling in Berlin (Geyer et al., 2001) and a remote site in the Baltic Sea (Heintz et al., 1996).

Nitrous acid, HONO, is an important generator of hydroxyl radicals (Stutz et al., 2004, Zhou et al., 2002) and HONO participates in heterogeneous reactions with aerosols (ref..) and HONO emission rates and chemistry generally are believed to be poorly characterized in CTMs. Nitrous acid is a strong climate forcing gas on a mole basis, adding incentive for HONO observations.

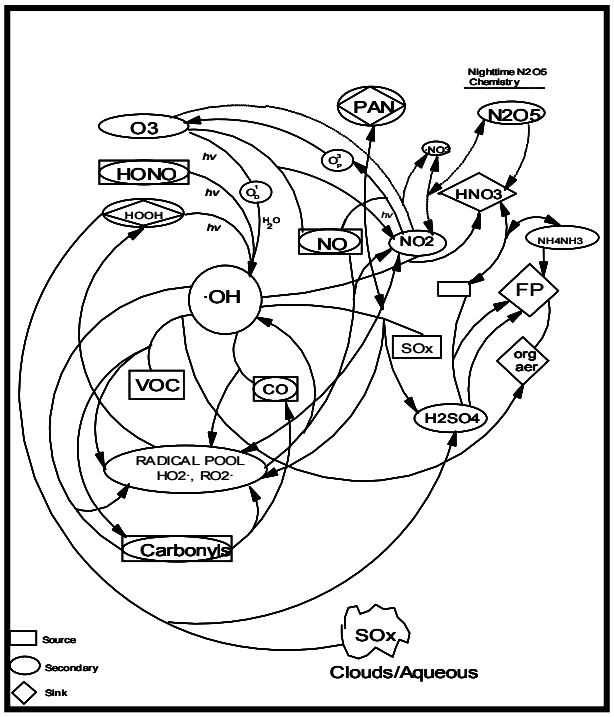

Figure 23. Overview of major atmospheric chemistry Pathways.

Mercury. Mercury remains one of the more complex atmospheric species with limited laboratory bench level information on atmospheric reaction rates and products. An initial effort organized through the NADP to provide routine dry mercury (elemental and gas and particulate bound) measurements offers centralized quality assurance and data management, an important consideration given complexities associated with mercury measurements. Speciated mercury measurements are important for diagnosing modeling applications and progress tracking of CAIR and CAMR emission reduction strategies.

CO and SO_2. Carbon Monoxide (CO) is a relatively conservative species useful for diagnosing a range of emission inventory and physical process characterizations in air quality models. Sulfur dioxide (SO_2) is a major component of sulfur budgets used in ecosystem deposition assessments and observations, in combination with particulate sulfate, provide a basis for evaluating model derived sulfate production underlying particulate matter mass and visibility estimates. Ambient SO_2 concentrations also are used in parameterization schemes characterizing ammonia deposition in air quality models. The available SO_2 and CO measurements are largely urban based and often in proximity to major source areas, limiting their representativeness of broader spatial domains. In addition, most of the current instruments were designed to capture high concentration levels for compliance purposes and do not capture reduced concentrations well mixed urban and rural environments. The NCore network will add modest improvements in coverage and detectability for SO_2 and CO.

Organic aerosol composition. The organic carbon fraction of the total aerosol budget will increase given the planned reductions in inorganic gaseous precursors from national mobile source and EGU targeted programs combined with a large pool of uncontrollable natural carbon from fires and biogenic emissions. Chemical speciation networks provide an

aggregated total organic carbon estimate, since it is not practical to resolve the full molecular spectrum of organic aerosols. Nevertheless, key molecular markers would assist a variety source apportionment applications and analyses delineating primary and secondary and modern and fossil derived organic fractions. Recognizing the resource burden of sample collection and analysis for organic composition, a modest grouping of sites and sampling frequencies should be considered to supplement or replace current routine analyses.

Aerosol physical properties. Interest in near roadway and ultrafine particle exposures, insight into particle nucleation processes and tracking change in aerosol size distributions associated with fuel transition programs (e.g., Wahlin et al., 2001) continue to raise the need for improved particle property measurements. Recent advances in instrumentation that produce relatively reliable and low cost estimates of particle number and surface area (need references from G. Allen) offer potential for routine network operations. Consideration of an initial 2-4 sustained sites to capture long term changes in particle size characteristics are recommended. Particle size measurements could be incorporated in a more focused effort characterizing a range of particle and gaseous attributes associated with near roadway environments.

Sentinel stations to link transport regimes. The relative contribution to North American air quality due to long-range pollutant transport should increase with rising emissions from developing economies in Asia and continued decreasing trends in North American emissions. Figure 3.7.1 and Table 3.7.1 describe a surface measurement network suitable for following the evolution of long-range transport of air pollution in the northern hemisphere. Both high elevation and near sea level sites are included. Each can typically serve multiple uses, including assessments for climate change, stratospheric ozone depletion, as well as long-range pollutant transport and model development. Coincident measurements of O_3 and aerosol components (nitrate, sulfate, organic and elemental carbon, trace metals), precursors of O_3 and aerosol (total reactive nitrogen, peroxyacetyl nitrate, and VOCs, sulfur dioxide) and atmospheric tracers (such as carbon monoxide and carbon dioxide and mercury) will strengthen long-range transport assessments and model evaluation efforts.

The network comprises a limited number of presently operating and proposed sites. The limits are a consequence of the pragmatic issues associated with servicing remote sites and a general lack of long-term funding commitments that compromise not only a needed expansion of adequate stations, but also the sustainability of existing platforms. Most of these stations are part of the Global Atmospheric Watch (GAW) program within the World Meteorological Office (WMO), and share data information systems and quality assurance protocols. While GAW enhances data consistency and access, funding for these sites is dependent on agency sponsorship, which is subject to changing research and program priorities and budget levels. Tracking long-term changes is a major advantage of surface stations and requires sustained support over decadal time periods. In addition, there are important locations (e.g. central and East Asia, East Coast of Asia, central North America and North American East Coast) that represent significant gaps in key transport corridors requiring additional support.

Table 3.7.1. Long-term Northern Hemispheric trace gas and aerosol surface stations.

Station	Location		Notes	Information
Alert	Canadian Arctic (210 m asl)	82.450°N 62.517°W	GAW global site	http://www.empa.ch/gaw/
Izana	Spain (Tenerife Is., West Coast Africa) 2360m asl	28.300°N 16.500°W	GAW global site	http://www.empa.ch/gaw/
Jungfraujoch	Switzerland 3580 m asl	46.548°N 7.987°E	GAW global site	http://www.empa.ch/gaw/
Mace Head	West Coast, Ireland, 5m asl	53.326°N 9.899°W	GAW global site	http://www.empa.ch/gaw/
Mauna Loa	Hawaii, U.S. 3397 m asl	19.539°N 155.578°W	GAW global site	http://www.empa.ch/gaw/
Minamitor-ishima	Japan (2000 km SE Tokyo) 8m asl	24.300°N 153.967°E	GAW global site	http://www.empa.ch/gaw/
Mt. Batchelor	Oregon, U.S. 2700m asl	43.979°N 121.687°W	University of Washington	http://research.uwb.edu/jaffegroup/modules/MBO/
Mt. Waliguan	China 3810 m asl	36.283°N 100.900°E	GAW global site	http://www.empa.ch/gaw/
Pallas	Finland 560m asl	67.974°N 24.116°E	GAW global site	http://www.empa.ch/gaw/
Trinidad Head	West Coast, CA, U.S., 107m asl	41.050°N 124.15°W	NOAA, U.S.	http://www.cmdl.noaa.gov/obop/thd/

Pt. Barrow	Alaska, U.S. 8 m asl	71.323°N 156.609°W	GAW global site	http://www.empa.ch/gaw/
Pico-NARE	Azores, Portugal 2225m asl	38.82°N 28.242°W	University of Azores	http://www.cee.mtu.edu/~reh/pico/
Sodankylä	Finland 180m asl	67.367°N 26.650°E	GAW global site	http://www.empa.ch/gaw/
Whiteface Mt.	New York, U.S. 1500m asl	44.4° N 73.9° W	ASRC SUNY, Albany	http://www.asrc.cestm.albany.edu/research/whiteface.htm
Zeppelin Mt.	Norway 474m asl	78.908°N 11.881°E	GAW global site	http://www.empa.ch/gaw/

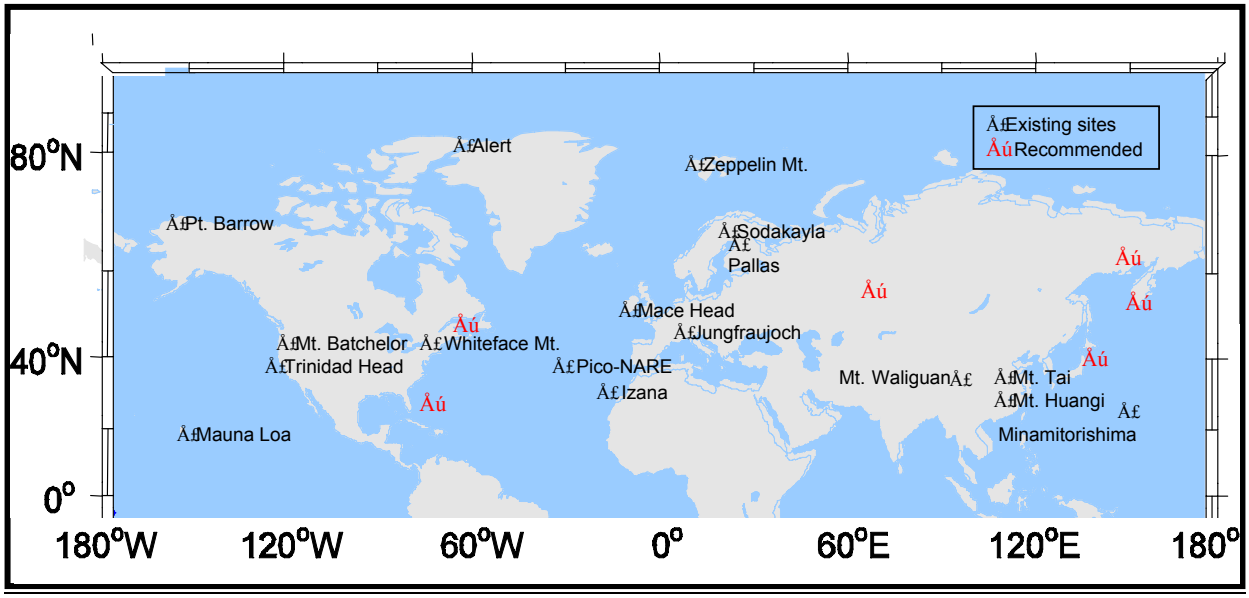

Figure 24. Surface site network for monitoring long-range transport of air pollutants.

Vertical Gradients And Atmospheric Column Characterization.

Inlet systems for surface based networks typically are positioned in the lower 10 meters of the atmosphere, which is representative of most human breathing zones. However, the lower 10 meters only occasionally represents mixing ratios of the planetary boundary layer which models attempt to characterize. Satellite total column data rarely is representative of surface based conditions. What observations gaps exist to better integrate surface and satellite based systems for the mutual improvement and leveraging of both systems in characterizing boundary layer air quality? From a satellite data perspective, adequate characterizations of surface and lower troposphere air quality can serve as evaluation tools. Conversely, through correlation techniques satellite offer potential to complement surface observations through spatial gap filling. Ideally, vertical gradient measurement of key species would serve as links between surface point and satellite systems. Investments that conceivably would leverage satellite data include:

- A sustained U.S. based aircraft campaign similar to the MOZAIC/CARIBE European effort that would produce routine vertical profiles of key trace gases and aerosols. Discussion are underway exploring expansion of Tropospheric Airborne Meteorological Data Reporting (TAMDAR) operated through privately held AirDat LLC to include chemical sampling;http://www.airdat.com/tamdar/faq.php);

- Deployment of fixed site LIDARS at key locations throughout North America to provide continuous profiles of back scattered light serving as a direct link between ground based AINOW $PM_{2.5}$ in –situ samplers and MODIS and CALIPSO satellite instruments. Such a network could build on the existing Regional East Atmospheric Lidar Mesonet (REALM) proposal (Hoff et al., 2003) that includes 6 sites in the Northeastern U.S. and Canada.

- Expansion of key ground based measurement systems that offer leveraging of satellite data. Emphasis would be placed on gloyoxal, formaldehyde, NO2, CO and SO2, consistent with planned NCore species.

Temporal Resolution

Chemical speciation. The routine aerosol chemical speciation networks provide 24 hour averaged sample periods collected every third or sixth day. This sampling design is adequate for supporting the annual $PM_{2.5}$ standard and regional haze programs in the United States but misses limits the number of associations to adverse health outcomes compromising support of epidemiological studies. Highly temporalized (e.g., hourly averaged) observations support evaluations of emissions and air quality model evaluations, and enhance application of source attribution techniques. Although the $PM_{2.5}$ supersite program spearheaded the testing and development of a broad suite of continuous aerosol chemistry instruments, there has not been a sustained effort to deploy and maintain semi-continuous chemical speciation instruments, with noted exceptions in the SEARCH/ARIES, Canadian and Regional Planning Organizations (RPOs) programs. Well defined market incentives and resource support for continuous

sampling technologies do not exist, and the proposed NCore Level 1 technology transfer component has not been deployed as a network infrastructure component.

North American networks have deployed over 500 routinely operating continuous $PM_{2.5}$ mass samplers. The use of these sites to characterize aerosol fields across broad spatial regimes is confounded by a diversity of instrument configurations and, within an instrument class, variable responses to different airshed and emission mixes. Efforts to harmonize these platforms through a combination of instrument modifications and correlation techniques would advance both the temporal and spatial resolution for mapping $PM_{2.5}$ mass. The recent reduction of the U.S. daily $PM_{2.5}$ standard from 65 to 35 μg/m3 will elevate the importance of the daily standard and add incentive to harmonize continuous instruments with gravimetric methods through national equivalency and regionally approved instrument demonstrations. While harmonization with reference methods may catalyze greater use of continuous data, it may detract from efforts to produce "true" atmospheric aerosol measurements, recognizing the variety of measurement induced artifacts (e.g., loss of semivolatile mass) associated with gravimetric techniques.

Satellites. Polar orbiting satellites provide extensive spatial coverage but affords limited temporal resolution as each orbiting platform is limited to two swaths per day. In response to the NRC's decadal survey on Earth Science Applications from Space, the interagency GeoTRACE proposal (Fishman et. al, 2005) calls for deployment of geostationary platforms focused on North America providing near continuous streams of chemical information comparable to that provided by NOAA's GOES (http://www.oso.noaa.gov/goes/index.htm) platforms, widely used for observing weather systems and meteorological forecasting. Agencies with stong interests in boundary layer characterizations (e.g., EPA) should consider sponsoring satellite missions and other atmospheric column characterization campaigns so that operational designs are matched efficiently with program objectives. The joint USGS – NASA Landsat program illustrates the successful partnering of an agency focused on surface resources using satellite data to better resolve surface information.

3.3 **Measurements Gaps in Terrestrial and Aquatic Systems.**

Chemical characterization of surface waters and soils benefits assessments by enabling parameterization of soil/water column processes used in a variety of watershed simulation models, providing inputs to biological response models, and serving as accountability indicators linking atmospheric deposition and biological responses. With the exception of the TIME/LTM program, there is a scarcity of sustained lake and stream water chemical observations relevant to assessing a systems response to atmospheric deposition changes. While the Time/LTM program is provides relatively broad spatial coverage of parts of the Northeastern U.S., analogous regional observations systems are not available. Sustained soil chemistry monitoring programs linking atmospheric deposition to sensitive water bodies and forest systems are not available.

Evolution of multi-media modeling systems with bi-directional feedbacks between soil, water and air interfaces will require soil and water column characterizations to parameterize mass transfer processes across media. Maintaining key multiple-media, multiple pollutant supersites, designed to bridge atmospheric, soil/water media and related biological parameters could serve as useful evaluation tools for model development and allow for long term accountability assessments.

3.4 **Recommendations for intensive field programs**

Intensive field campaigns accommodate the probing of atmospheric processes with an assortment of measurement technologies capturing features such as the coincident characterization of vertical and surface based chemistries typically not covered in routine programs. Due to the complexity of most field campaigns, access to raw and processed data often is not readily available usually resulting in a limited "expert" user community either directly involved in the studies or in close collaboration with related projects. There are data archiving efforts through NARSTO that generally are not relied upon by a different user community. While it may not be practical to organize data from the myriad of special field campaigns, some modest efforts would increase the value of these programs in supporting air quality assessments. As discussed earlier, there has not been an inventory and synthesis of findings since the NARSTO 2000 ozone assessment. In place of an updated synthesis, consideration should be given to maintaining a dynamic inventory of field campaigns that provides basic meta data level information base regarding program objectives, key finding, participants, spatial and temporal extents and listing of measure parameters. Increasing the awareness of these studies is a first step in gleaning added value and perhaps sustained support. Consideration also should be given to periodic design of field campaigns to explicitly evaluate current and dynamic model performance.

Historically, model evaluation has been based on availability of data sets, which as discussed above generally have not been designed for model evaluation. Intensive field campaigns often are perceived as model evaluation studies although model evaluation usually is a secondary objective of these programs. The demands on characterizing environmental states grows with an interest in integrating across pollutant groups, environmental media and spatial and temporal scales. Given the enormous resource requirements of observational systems, a gradual reliance

on models will emerge to provide basic characterizations that traditionally have been met through observations. Consequently, an efficient use of observation resources will consider model evaluation as a primary monitoring objective.

3.5 Data gaps in exposure and health effects information.

3.6 Integration across accountability indicators.

Accountability assessments rely on sustained long term observations to capture a system's response to emissions changes that, ideally, adequately cover indicator categories throughout the source to effects continuum (Figure ?). From an air quality perspective, significant gaps exist in precursor species bridging source emissions and ambient concentrations of targeted secondarily formed species such as ozone and $PM_{2.5}$ mass.

Although a number of observation gaps relevant to accountability assessments have been identified, it's useful to consider lessons learned from national ozne mitigation policies and the use of observation systems used in retrospective assessments to support prospective designs for future accountability efforts.

The addition of VOC measurements through the PAMs program in the early 1990s in theory addressed concerns regarding gaps in ozone precursor observations raised the 1991 NAS ozone study, "Rethinking ozone problem in urban and regional air pollution." Unfortunately, the PAMS program emphasized VOC technology improvements and measurements with a marginal addition of nitrogen measurements with no technological advances. During the PAMS implementation period, a general scientific consensus emrged regarding the importance of NOx in abating ozone, conveyed through the NAS study. Air program management strategies were modified and NOx reductions, especially from major EGUs in the Midwest and Eastern U.S., became a dominant national strategy resulting in downward trend of NOx emissions starting in the late 1990's (Figure..). Despite over 15 years of lead time, the lack of investments in nitrogen observations precluded thorough assessments of the efficiency of the NOx`SIP Call. Tracking nitrogen changes offers more insight relative to urban based VOCs for assessing the effectiveness of major emission reductions strategies targeting ozone abatement. Many recent accountability analyses (EPA, 2005; Gigo et al., 2006; Frost et al., 2006, Gilliland et al., 2007) addressing the NOx SIP CALL relied largely on inferential analyses based on ozone observations (Figure ?) combined with back trajectory analyses and modeling results,and generally illustrate success of NOx reductions efforts. The Frost study (Figure ??) utilizing satellite NO_2 data is the only analysis to date addressing ambient nitrogen values, a commentary on both the utility of satellite data and scarcity of ground based observations. Ideally, a network of reactive nitrogen (NOy – which includes most of the gas phase transformation products of originally emitted NOx) monitors in representative sites responsive to different emission source regions would allow for more direct confirmation of expected emissions to ambient ozone responses, as well as diagnosing of unexpected outcomes. Ironically, the minimal response of ozone to VOC dominated emission reductions in the late 1980s and early 1990s often is cited as an example of missing key indicators to assess and diagnose program progress responsible for a lag in implementing NOx reductions.

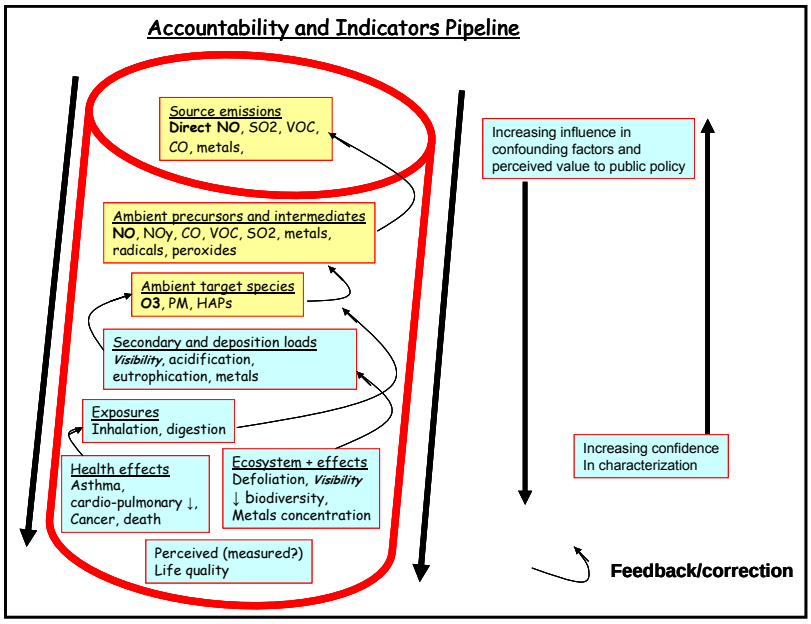

Figure 25. Descending pipeline of accountability categories illustrating gradual increase in confounding factors affecting association between categories.

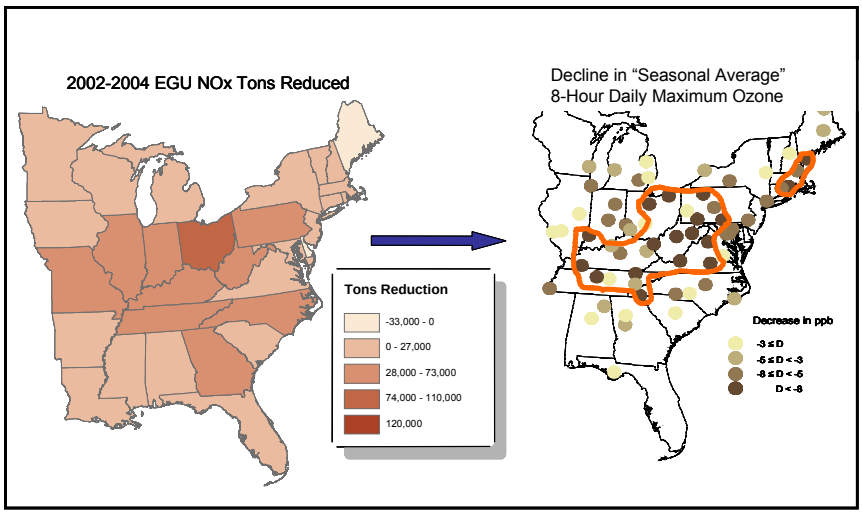

Figure 26. Association between ozone season power plant NOx emission reductions and observed ozone for from 2002 -2004. An average 1.1%/year rate of decline in ozone between 1997 and 2002 increased to 3.1%/year between 2002 and 2004, the period associated with deployment of NOx SIP CALL reductions (EPA, 2005).

Prospective monitoring needs. The NOx SIP CALL and earlier VOC focused control efforts for ozone are examples of missed monitoring opportunities where available information was mined to develop inferential explanations of program outcomes. Looking forward, prospective assessments addressing impacts of yet to be deployed emission strategies should link back to the original assessment work, generally future year air quality modeling predictions, as a guide for ambient atmosphere monitoring design. Monitoring can be thought of as a tool to support the central question underlying accountability assessments: Does the system respond as predicted and, if not, what modifications are suggested? A monitoring design addressing this

question shares elements with but can differ from a design intended to characterize compliance with a standard, support initial development of an emissions strategy or quantify population exposure.

Basic monitoring considerations addressing accountability include identifying:

- locations of expected high concentration (or deposition) changes,
- areas in close proximity to receptors of concern (e.g., high populations, sensitive ecosystems),
- atmospheric species linked closely with emissions signals (e.g., precursor gases and resulting transformed species),
- atmospheric species linked closely with an ambient target or standard, and
- establishing a baseline reference and extending measurement duration throughout deployment period of interest.

A logical starting point for addressing monitoring gaps is to inventory major emission reduction programs expected to be implemented over the next two decades and assess the adequacy of existing monitoring assets to address future estimates for emission and air quality changes. Analysis of the underlying air quality modeling and related technical documentation underlying the programs in Table 2 would assist in developing a monitoring strategy cognizant of expected atmospheric perturbations. Such a strategy would consider various scales of observation resolution in addition to parameters of expected change most relevant to a specific program being implemented. Observations of NOy, SO_2, and gaseous mercury to address regional and rural spatial gaps discussed above address ongoing needs for major regional and national air program strategies. Near field roadway exposures in current limited time frames generally are poorly characterized. More challenging is the development and deployment of a monitoring strategy balancing limited resources and the desire to introduce as yet non routine technologies to characterize key attributes of near roadway environments. Continued desulphurization of diesel fuels should reduce particle numbers (Wahlin et al, 2000) in near roadway environments, yet an observation system to track this change is not in place. Energy policy striving to reduce dependence on overseas oil or to reduce climate forcing gases are well integrated with air quality management practice. For example, increased penetration of ethanol based fuels should elevate acetaldehyde and PAN levels in roadway environments, and possibly increase efficient climate forcing N_2O in corn growing regions subjected to increased fertilization (recent reference).

Table 2. Planned air program management strategies and monitoring implications. [ongoing project…]

Emission/energy strategy	Implementation period	Spatial domain	Predicted emission changes	Monitoring implications
CAIR				
CAMR				
MSAT				

3.7 Merging observational systems and predictive models.

[write-up coming that discusses the various relationships of models and observations, ranging from basic evaluations to different levels of data assimilation; the point being the need to consider observational design in conjunction with model applications.]

Increasingly, models and observations are being used together in a variety of ways partly due to advances in computational efficiencies and also in response to the complexities presented of multiple scales, pollutants and environmental media. The integration of chemical observations and chemical transport models (CTMs) is evolving and shares common attributes with weather characterization (and forecasting), although lagging in maturation. Observations by themselves lack adequate resolution (space, time and composition) to service integrated assessments, and models in isolation rarely are perceived with confidence. Observation and model integration efforts range from using measurements to evaluate model performance to dynamic assimilation analogous to four dimensional data assimilation (FDDA) used in meteorological models, with several variations and intermediate levels of integration. Examples of recent and emerging integration of models and observations include:

> Inverse emission modeling (e.g., ammonia North America; isoprene, CO, NO_2 globally)
> Surface fusion (e.g., PHASE daily 12 km CMAQ and AQS (O3, $PM_{2.5}$) data
> Direct assimilation of chemical observation for air quality forecasting applications (Carmichael reference)

The use of the term data assimilation has taken on multiple definitions, ranging from any use of observations (e.g., model evaluation) to full FDDA raising some confusion among meteorologists who limit the term assimilation to FDDA type applications. This discussion on data gaps related to models will focus on the use of observations to address model evaluations needs.

Measurement Gaps relevant to air quality model evaluation

[many of the graphs are repetitive from earlier chapters]

Model evaluations must rely on observational sets often not designed to support modeling assessments. Consequently, there a numerous incommensurabilities between model evaluation needs and observations. Simple examples include:

- Very limited vertical gradient and atmospheric column observations despite the substantial levels of elevated mass not represented by surface measurements;
- heavily skewed distribution of observations in urban areas leaving substantial surface gaps throughout the modeling domain,
- absence of important process "indicators" such as nitrogen dioxide, formaldehyde, and radicals (hydroxyl, hydro- and organic peroxy), and
- near field representativeness associated with most "point" measurements compared with volume averaged cells of models

In addition to resource and technological constraints hindering acquisition of desired model oriented observations, our routine networks, understandably, emphasize observations of relatively direct regulatory consequence - the breathing zones of populated areas. However, there does exist an enormous body of routine air quality observations (Figure 1) which combined with periodic intensive field campaigns and satellite missions provide compositional, temporal and vertical richness often mined for operational and diagnostic model evaluations. This discussion addresses opportunities for strengthening the observation gaps for model evaluation purposes.

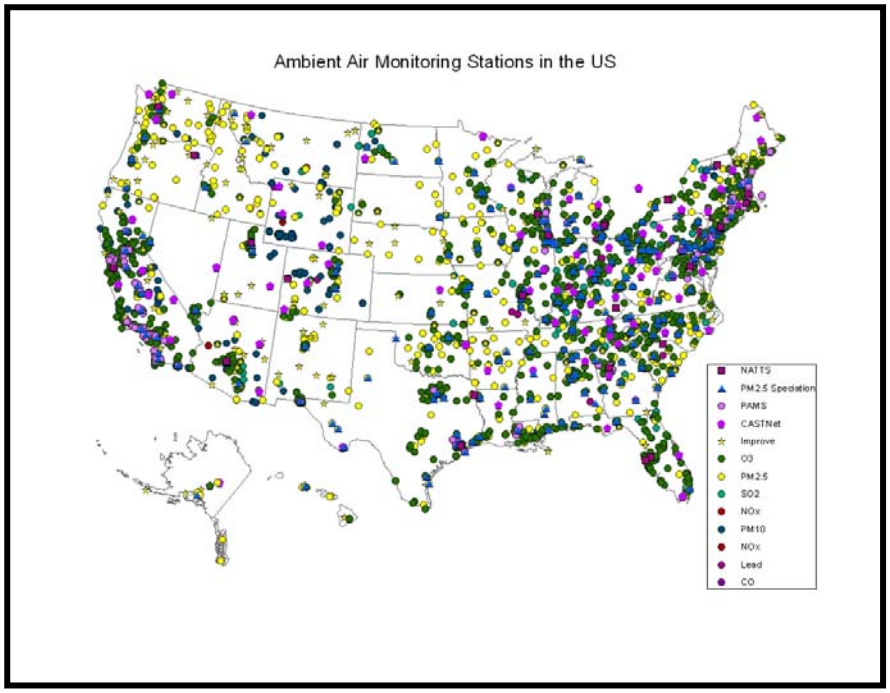

Figure 27. Aggregation of United States surface air monitoring stations.

Sequencing model evaluation

Ideally, the model evaluation process would follow a logical series of component by component evaluations starting with input fields (boundary conditions, emissions, meteorology), progressing through probing modeled treatment of physical properties (advection and dispersion schemes, vertical layers and mixing heights) prior to addressing behavior of secondarily formed gaseous and aerosol species that have inherent nonlinearities (Figure 2). The reason for this is because system thermodynamics and physical processes affect the response patterns of chemical systems far greater than the reverse impact of chemistry on physics – especially in nonlinear systems governing ozone and secondary aerosol formation. There may be inherent logic in following a Lagrangian perspective by sequencing evaluation steps following mass flow from emissions through ambient and deposition fields. In practice, however, evaluations tend to focus on terminal transformed species (ozone and secondarily formed aerosols) because of the availability of policy relevant observations. Consequently, the ability to diagnose the causes of a particular model behavior is limited by information gaps compromising confidence that preceding processes are adequately parameterized.

This section provides an overview of the observational assets available and significant gaps organized around a component based model evaluation approach. Meteorological observations are addressed initially, recognizing that confidence in the model's ability to adequately characterize PBL heights and advective and dispersive mixing processes fosters increased confidence in subsequent evaluation of emission inputs and ambient (conservative species) fields. Similarly, confidence in well constructed temperature, radiation and water vapor fields helps establish greater confidence in evaluation efforts addressing atmospheric chemistry and natural emissions processes.

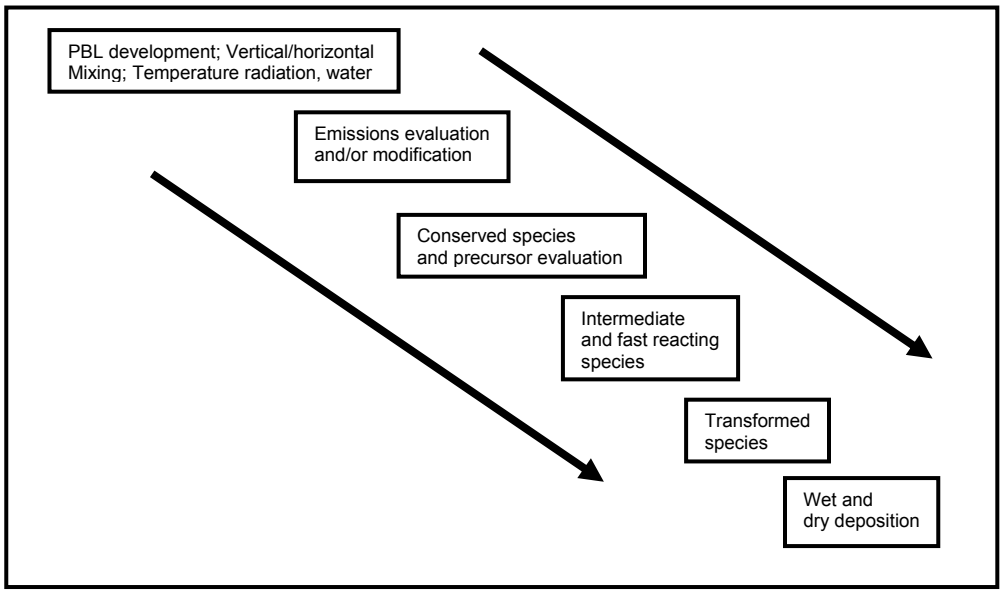

Figure 28. Idealized sequence of model evaluation steps on a component basis following mass flow.

Evaluating Model Input Fields: Meteorology, Emissions and Boundary Conditions

Meteorology.

Modern meteorological models assimilate meteorological data to designed to adhere to mass and heat conservation principles and improve accuracy relative to observations. Nevertheless, the resulting meteorological model outputs and subsequent processing of convection and diffusion parameters and vertical layer formulation within the air quality model remain "calculated" fields requiring independent evaluation through observations. Although there is a wealth of surface based observation systems, upper air and vertical profile observations of temperature, winds and planetary boundary layer (PBL) heights are more relevant to diagnosing physical processes of large Eulerian systems. This discussion will focus on systems available to construct observed PBL heights, fundamental to basic mixing process and emissions evaluation efforts.

PBL height (mixed layer height) is a derived quantity based largely on vertical temperature profiles and refractive index structure parameters, Cn^2. Relevant observed indicators of PBL depth include aerosol and gaseous chemistry profiles.

Observations for evaluating PBL heights.

Radisosondes, radar profilers and ceilometers. The Meteorological Data Ingest System (MADIS - http://madis.noaa.gov/) is an integrated system incorporating observations from a variety of surface based, vertical profile and satellite networks that provides a centralized source of observations servicing evaluation efforts. The deployment of NOAA's profiler network (NPN - http://www.profiler.noaa.gov/npn/) over the last decade has added near continuous stream of wind vector data to complement the National Weather Service's (NWS) radiosonde network providing twice daily soundings spread across nearly 100 locations throughout the United States. The NPN includes 35 unmanned Doppler Radar sites profiling the troposphere (10-15 km) and concentrated in the central United States designed for violent weather forecasting. The Photochemical Assessment Measurement Stations (PAMS) program and other air agency efforts support a network of radar profilers (Figure 3) that provide highly resolved wind profiles and Cn^2 coefficients of the boundary layer (up to 5 km). The boundary layer radar profilers, especially when complemented by temperature profiles generated by Radio-Acoustic Sounding System (RASS) offer a source of relatively untapped data for model evaluation.

The radiosonde network lacks adequate temporal resolution to adequately characterize diurnal development and collapse of PBL heights. Radar profilers are an underutilized resource which has inadequate spatial coverage and lacks a consensus methodology to synthesize raw data into spatial and temporal observation patterns conducive to model evaluation. Cloud height measurements through ceilometers are reasonable PBL depth indicators for non clear sky conditions, but a spatially extensive network for broad application is not available. Since 2004, over 400 commercial aircraft have been collecting meteorological variables (temperature, pressure, RH, winds) as a part of the tropospheric Airborne Meteorological Data Reporting (TAMDAR - http://www.airdat.com/./tamdar/index.php) system. While TAMDAR is designed

to provide near real time data for forecasting, the system provides valuable vertical profile temperature data (and other variables) during ascents and descents that potentially can be synthesized to fill in temporal and spatial gaps of ground based profilers.

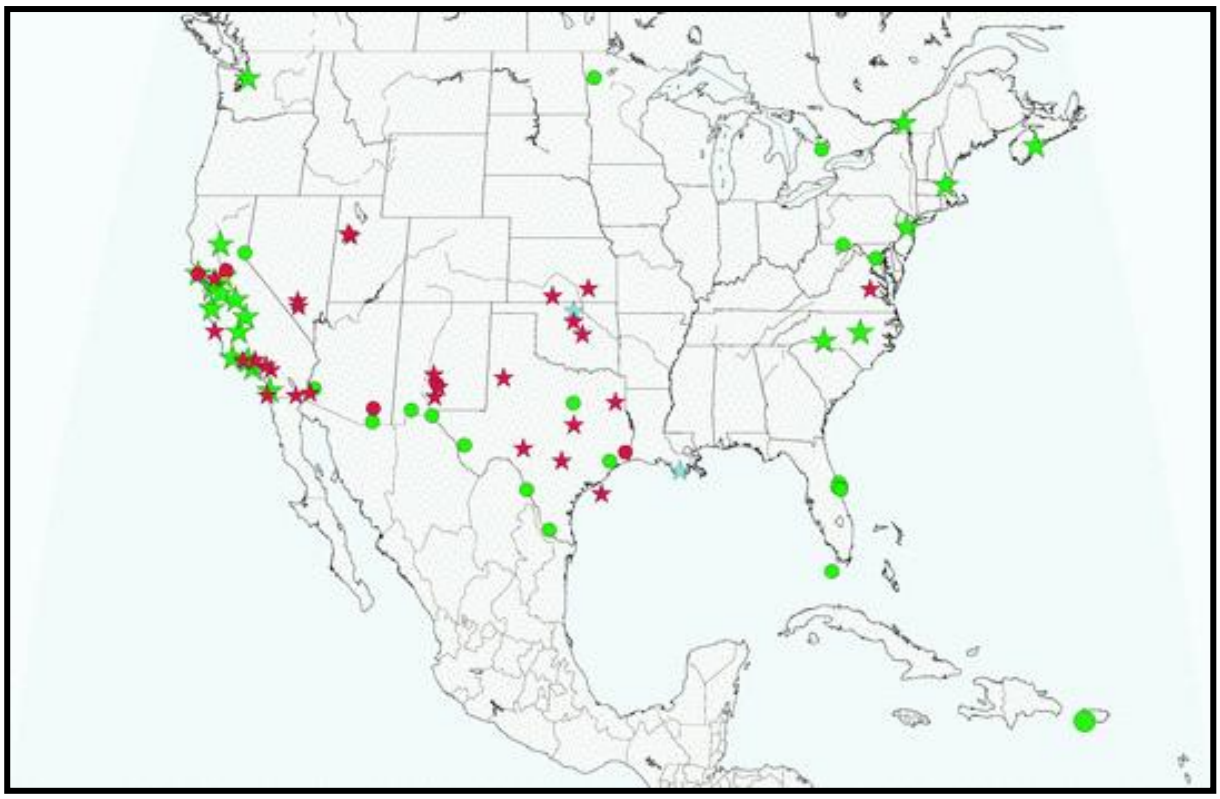

Figure 29. North American air quality profiler network (**http://www.madis-fsl.org/cap/profiler.jsp**).

Aerosol and gaseous data profiles. PBL depths can be inferred through vertical gradient concentration analyses of aerosols and gases where the rapid vertical gradient change is driven largely by PBL height. Ground based Light Detection and Ranging (LIDAR) operate continuously and provide point information on daily evolution of the PBL. However, a sustained LIDAR network is not available and probably not a cost effective approach relative to building on existing wind profiler networks. Very limited gaseous species profile data is available, limited to aircraft sampling conducted during intensive field campaigns.

Satellite applications. Remote sensing information from NOAA's geosynchronous satellites offers high time resolution data across most of North America on cloud coverage and surface temperatures. Reanalysis of these fields can improve cloud attenuation effects on photolysis rates and near surface heat and fluid dynamics characterizations.

Recommendations.

1. Provide a centralized data repository and synthesis system for boundary layer profiler and TAMDAR data.

2. Develop an inventory of boundary layer radar profilers and RASS systems and establish sustained funding to maintain operations. Conduct an assessment of existing boundary layer profiler network and add profilers in areas that strongly influence model response behavior.

Emissions

The recent NARSTO emission inventory assessment (reference needed) prioritized ten areas requiring improvement: Fine particles and their precursors, Toxic and hazardous air pollutants, Onroad motor vehicles, agricultural sources, especially ammonia, Biogenic sources, Petrochemical and other industrial facilities, Off road mobile sources, Open biomass burning, Residential wood combustion, Paved and unpaved road dust. From a model evaluation perspective, emission inventory priorities should address improvement in categories addressing characterization of physical processes (e.g., CO) followed by precursor species (e.g., NOx, SO_2, VOC) driving chemical transformations ozone and aerosols. Evaluation of carbon monoxide (CO); nitrogen, nitrogen oxides (NOx) and ammonia (NH_3), sulfur dioxide (SO_2) and VOC budgets arguably address the needs of a variety of applications – CO serving as a conservative tracer to address mixing and geometrical properties; N, SO_2 and VOC emissions to address ozone secondary aerosol formation, visibility and ecosystem deposition. Since these four categories consititute most of the gaseous load to the atmosphere (with noted exceptions for climate forcing gases; methane, carbon dioxide), their accuracy is required given the multiple interactions across pollutant species. Specific air toxics applications can be thought of as requiring tailored downstream evaluation efforts that benefit from these generalized emission improvements that add confidence in the physical and chemical processes driving most modeled species. Naturally, as the priority of a particular category increases (e.g., mercury or other metals), further species specific evaluation and emission is warranted.

In broad terms, the major emission categories in the United States are electrical generating units (EGUs), transportation (onroad and offroad) and natural/agricultural sources (biogenic VOCs; ammonia from fertilization and livestock waste; aerosol carbon, CO and NOx from fires, wild and prescribed). The first two categories benefit from specific emission modeling systems, (IPM and MOBILE, spell out and reference) that are updated frequently and can be exercised at relatively low cost on a yearly basis. Natural and agricultural sources are not as well categorized due to the complexity and stochastic attributes of natural systems, in addition to a direct regulatory driver. From an evaluation perspective, natural emissions should be considered as important as anthropogenic sources as all emission fields potentially affect the modeling systems ability to characterize base case events and dynamic responses to emission perturbations.

Emission Inventory evaluation through measurement programs generally can be broken into four categories: (1) direct near source measurements; examples include ammonia flux measurements (Aneja, et. al, 2003) and remote sensing of roadway emissions through open path FTIR methods (Bradley et al., 2000) (2) dedicated mass balance studies in controlled environments such as roadway tunnels (ref.), (3) inference analysis based on ambient measurements, typically in the form of statistical relationships through source apportionment models or simple ratio analysis (ref.) and (4) inverse modeling using ambient measurements

with assumed well characterized model physics (Gilliland et al, 2003). Overlaps exist across these methods as well between source methods (ammonia flux measurements) used to develop emission factors and evaluate emissions. Also, the addition of Continuous Emission Monitors (CEMs) required through promulgation of major rules such as the NOx SIP CALL, the Clean Air Interstate and Mercury rules (CAIR and CAMR) have enabled yearly adjustments of major sources in the base inventory, which typically is generated on three year cycles.

Recommendations:

1. Periodic highly focused emissions evaluation studies should be considered part of our national programs, jointly shared by the emission inventory, source categorization and ambient monitoring disciplines. Examples of focused studies on different emission categories include:

    a. tunnel studies for on-road mobile source emissions in major transportation corridors;

    b. near roadway campaigns to elucidate emission patterns of aerosol size distributions, semivolatile organics, re-entrained road dust and specific VOC HAPs (acrolein, formaldehyde, 1,3 butadiene, benzene);

    c. direct and fugitive emissions characterizations for major industrial sources;
    d. ammonia flux studies covering fertilization and livestock practices sectioned by seasonal and geographic characteristics;
    e. air quality sampling during prescribed fire events to develop speciated chemical profiles segmented by source type; and
    f. near canopy sampling for biogenic VOCs across different forest types and meteorological conditions.

2. Develop surface based observations to complement satellite based vertical column observations of key emission indicator species. Satellites provide broad spatial coverage of NO_2, SO_2, HCHO, and CO with potential for evaluating emission estimates and improvements through inverse modeling techniques. This practice has been applied for global modeling efforts, particularly in areas with limited bottom up emissions information (Martin et al., 2003; Fu et al., 2007; Palmer et al., 2006). By comparing observed and calculated total column emissions loadings, satellite data can provide a useful top-down constraint in the emissions evaluation process. Our surface based networks lack adequate spatial coverage of these trace gas species. The combination of ground and satellite based observations leverages the utility of each system by potentially expanding spatial coverage through associations between surface and satellite observations and developing greater confidence in satellite measurements. Formaldehyde serves as an indicator for biogenic isoprene emissions and there are well established relationships between emitted nitrogen oxide and transformed nitrogen dioxide.

Boundary Conditions.

The expansion of modeled spatial and time domains has reduced the relative sensitivity to initial and boundary conditions. However, the increased understanding of hemispheric transport combined with accelerated emissions growth of distant economies and gradual lowering of targeted air quality standards elevates the importance of boundary conditions. Global scale air quality models increasingly are being applied to generate boundary values for regional scale models. Therefore, the availability of data to evaluate global scale models is of direct importance to regional scale applications. High elevation monitoring sites that minimize influences from boundary layer disengagement due to marine and surface layer surface effects and local emission sources are preferred locations for characterizing boundary conditions and assessing strong advective transport processes.

Figure 4 and Table 1 describe a surface measurement network suitable for following the evolution of long-range transport of air pollution in the northern hemisphere. Both high elevation and near sea level sites are included. Each can typically serve multiple uses, including assessments for climate change, stratospheric ozone depletion, as well as long-range pollutant transport and model development. Coincident measurements of O_3 and aerosol components (nitrate, sulfate, organic and elemental carbon, trace metals), precursors of O_3 and aerosol (total reactive nitrogen, peroxyacetyl nitrate, and VOCs, sulfur dioxide) and atmospheric tracers (such as carbon monoxide and carbon dioxide and mercury) will strengthen long-range transport assessments and model evaluation efforts.

The network comprises a limited number of presently operating and proposed sites. The limits are a consequence of the pragmatic issues associated with servicing remote sites and a general lack of long-term funding commitments that compromise not only a needed expansion of adequate stations, but also the sustainability of existing platforms. Most of these stations are part of the Global Atmospheric Watch (GAW) program within the World Meteorological Office (WMO), and share data information systems and quality assurance protocols. While GAW enhances data consistency and access, funding for these sites is dependent on agency sponsorship, which is subject to changing research and program priorities and budget levels. Tracking long-term changes is a major advantage of surface stations and requires sustained support over decadal time periods. In addition, there are important locations (e.g. central and East Asia, East Coast of Asia, central North America and North American East Coast) that represent significant gaps in key transport corridors requiring additional support.

Satellite data have been incorporated in various aspects of global scale air quality modeling through inverse emissions calculations, constraining vertical column fields and providing qualitative, visual checks on model behavior.

Table 1. Long-term Northern Hemispheric trace gas and aerosol surface stations.				
Station	Location		Notes	Information
Alert	Canadian Arctic (210 m asl)	82.450°N 62.517°W	GAW global site	http://www.empa.ch/gaw/
Izana	Spain (Tenerife Is., West Coast Africa) 2360m asl	28.300°N 16.500°W	GAW global site	http://www.empa.ch/gaw/
Jungfraujoch	Switzerland 3580 m asl	46.548°N 7.987°E	GAW global site	http://www.empa.ch/gaw/
Mace Head	West Coast, Ireland, 5m asl	53.326°N 9.899°W	GAW global site	http://www.empa.ch/gaw/
Mauna Loa	Hawaii, U.S. 3397 m asl	19.539°N 155.578°W	GAW global site	http://www.empa.ch/gaw/
Minamitor-ishima	Japan (2000 km SE Tokyo) 8m asl	24.300°N 153.967°E	GAW global site	http://www.empa.ch/gaw/
Mt. Batchelor	Oregon, U.S. 2700m asl	43.979°N 121.687°W	University of Washington	http://research.uwb.edu/jaffegroup/modules/MBO/
Mt. Waliguan	China 3810 m asl	36.283°N 100.900°E	GAW global site	http://www.empa.ch/gaw/
Pallas	Finland 560m asl	67.974°N 24.116°E	GAW global site	http://www.empa.ch/gaw/
Trinidad Head	West Coast, CA, U.S., 107m asl	41.050°N 124.15°W	NOAA, U.S.	http://www.cmdl.noaa.gov/obop/thd/
Pt. Barrow	Alaska, U.S. 8 m asl	71.323°N 156.609°W	GAW global site	http://www.empa.ch/gaw/
Pico-NARE	Azores, Portugal 2225m asl	38.82°N 28.242°W	University of Azores	http://www.cee.mtu.edu/~reh/pico/
Sodankylä	Finland 180m asl	67.367°N 26.650°E	GAW global site	http://www.empa.ch/gaw/
Whiteface Mt.	New York, U.S. 1500m asl	44.4° N 73.9° W	ASRC SUNY, Albany	http://www.asrc.cestm.albany.edu/research/whiteface.htm
Zeppelin Mt.	Norway 474m asl	78.908°N 11.881°E	GAW global site	http://www.empa.ch/gaw/

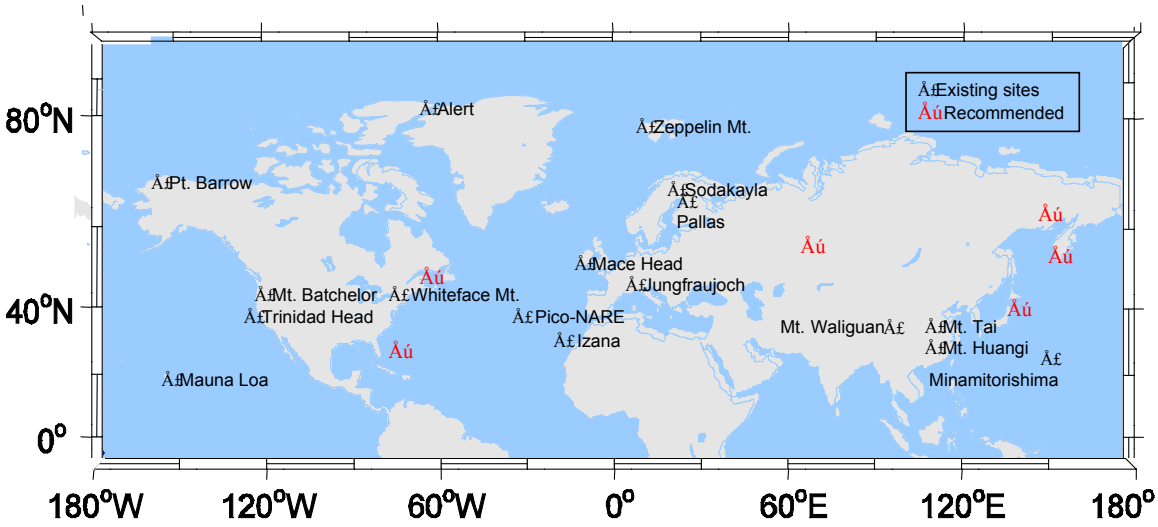

Figure 30. Current and proposed site network for monitoring long-range transport of air pollutants (source, LRTAP HTAP 2007 interim assessmentreport).

Data Needs Relative To Evaluating Ambient Concentrations

Ambient Fields: Conservative tracers and emission precursors.

There are clear overlaps between evaluating emissions and mixing processes. Each is dependent on the other and judgement regarding the relative confidence in emissions or mixing processes determines the perspective on what is being evaluated. For example, temporal and spatial CO patterns enable assessment of PBL depth and other mixing processes or emissions fields generated by combustion based sources, depending on the relative confidence in meteorology or emissions. Or, the model's ability to capture ambient fields of conservative species and precursors provides confidence in the combined effects of mixing and emissions.

Elemental carbon (EC) is a useful conservative tracer measurement, however, interpretation of EC is defined by measurement and analysis protocols which are not uniform across the networks and subject to periodic modifications. In addition, EC typically is a 24 hour average value collected on an every 3 day basis consistent with other aerosol components. Because our ambient observation networks focus on the more compliance relevant transformed species (ozone and $PM_{2.5}$), there are considerable gaps in important trace gas measurements in our surface networks. While the conservative nature of CO minimizes corrections from transformation processes, ambient concentration fields of major precursors, NOx, SO_2 and VOCs are important model evaluation species. The addition of spatially representative, multiple pollutant stations through the new NCore network will provide an initial 75 stations (Figure 5) measuring trace level concentrations of CO, SO_2, NH_3, NO and NOy as well as aerosol mass and composition across the United States.

Recommendations:

1. Enhance current plans for the NCore network by adding stations in key transport corridors and locations addressing significant network spatial gaps.
2. Implement routine monitoring to capture vertical gradients of precursor species using commercial aircraft flights or other approaches.
3. Similarly, enhance surface and vertical profiling monitoring programs for formaldehyde and true nitrogen dioxide. These two species provide an opportunity to leverage existing and planned satellite remote sensing campaigns and provide indicators for NOx and biogenic isoprene emissions.

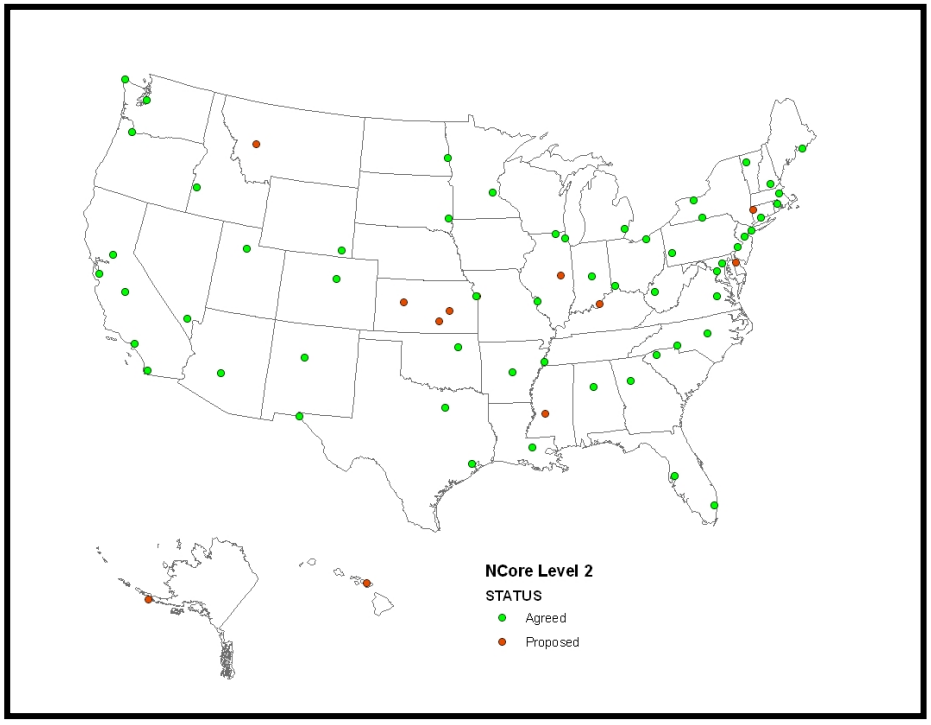

Figure 31. Preliminary map of NCore Level 2 multiple pollutant stations.

Ambient Fields: Key chemical indicator species (radicals, reactive intermediates and sinks)

Certain fast reacting intermediate species [e.g., hydroxyl (OH•), hydroperoxy (HO2•, organicperoxy (RO2•) and nitrate (NO3•) radicals; peroxides (hydrogen and organic; HOOH, ROOH), formaldehyde (HCHO) and true nitrogen dioxide (NO2)] provide insight into the ability of chemical mechanisms to characterize important gaseous and aerosol phase reactions (Figure 6). Nitric acid, HNO3, is an important sink species and along with peroxides offer insight into the relative reaction limiting roles of VOCs and NOx on ozone formation. Further inclusion of transformed products such as total reactive nitrogen, NOy, and NOz (NOy- NOx) are used in ratio groupings supporting diagnostic evaluations and observational based models (Silllman et al., 2002). Significant measurement complexities exist due to limited atmospheric life times and analytical interferences. Consequently, routine observation networks provide minimal coverage limited to formaldehyde through the PAMS and air toxics

programs. Routine network NO_2 measurements are confounded by interferences from various oxidized nitrogen compounds, resulting in variable positive biases in the data base. Peroxides and radicals occasionally are measured in intensive field campaigns, but typically require research grade efforts. The SEARCH network in the southeastern U.S. performs nitric acid measurements, although the technology for semi-continuous monitors does not appear ready for widespread network deployment. Despite the importance of intermediate species observations, the general difficulty of accurately measuring these species (with some exceptions) prevents, at this time, incorporation into traditional networks. Nitrous acid, HONO, is an important generator of hydroxyl radicals (Stutz et al., 2004, Zhou et al., 2002) and HONO participates in heterogeneous reactions with aerosols (ref..) and HONO emission rates and chemistry generally are believed to be poorly characterized in CTMs. Nitrous acid is a strong climate forcing gas on a mole basis, adding incentive for HONO observations.

Recommendations:

1. Complete method development and testing of a routinely operating true nitrogen dioxide monitor and deploy as part of the NCore program;
2. Increase formaldehyde measurement program as this species not only adds value from an isoprene emissions perspective, but also supports atmospheric chemistry evaluations;
3. Initiate periodic but sustained HONO measurements in one or two urban centers preferably with DOAS to capture diurnal profiles; and
4. Conduct periodic intensive field campaigns that include intermediate species to diagnose atmospheric chemistry processes and, over time, assess changes in atmospheric chemistry resulting from emissions and climate alterations.

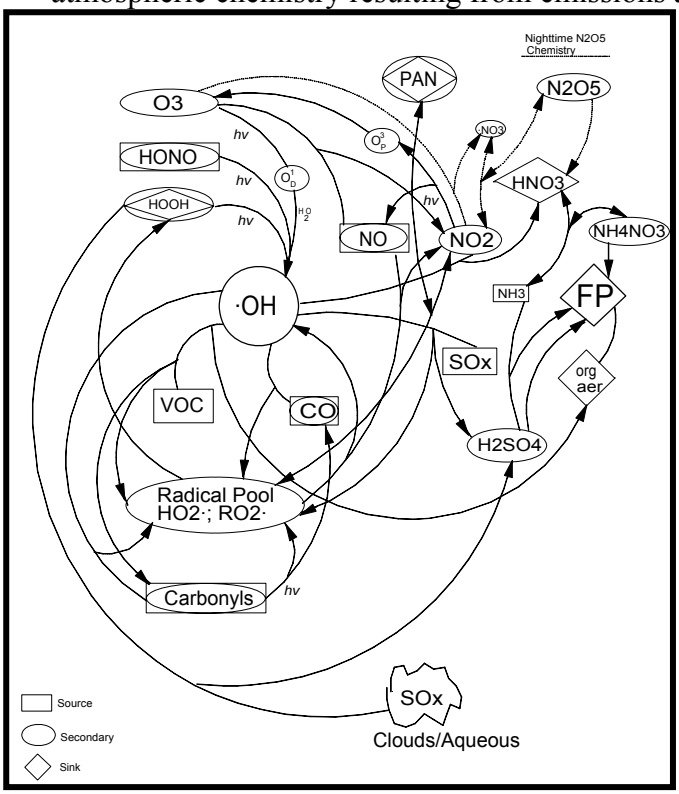

Figure 32. Spaghetti diagram depiction of key atmospheric chemistry pathways responsible for ozone and secondary aerosol formation.

Ambient Fields: Secondary products

Secondarily formed species such as ozone, organic carbon, sulfate, nitrate, ammonium and mercury are end products of most modeling applications. Consequently, the ability to characterize these pollutants tends to be more fully integrated with other physical and chemical processes, relative to more conservative species. Fortunately our ground based ambient air networks provide relatively rich spatial coverage for ozone, sulfate, nitrate and total organics carbon as these species often are direct (or mass components of) regulatory indicators. In addition, precipitation chemistry networks such as the National Atmospheric Deposition Program (NADP) and Mercury Deposition Network (MDN) provide relatively adequate coverage of nitrogen, sulfur and mercury aqueous phase ions. Routine and sustained observations for reactive nitrogen (NOy) and divalent mercury gas (Hg^{+2}) are limited to region specific efforts such as SEARCH. Although direct measurements of major NOy species, peroxyacetyl nitrate (PAN) and nitric acid, are preferable, reactive nitrogen serves as an efficient indicator of transformed NOx emissions, useful for balancing nitrogen mass for model evaluations and is an accountability metric for assessing impact of NOx emission strategies. Particulate ammonium measurements remain confounded by variable levels of filter based ammonia volatization, compromising estimates reduced nitrogen budgets. Speciated dry mercury (Hg^0 and Hg^{+2} gases and particulate Hg) observations also are key mass balance and accountability metrics, and reflect major gaps relevant to mercury related assessments. Speciated organic aerosol measurements remain limited to specialized research field campaigns. Observations enabling delineation of secondary and primary organic carbon; fossil derived and modern; and biogenic and fire derived would enable ongoing evaluation and improvement of secondary organic aerosol (SOA) mechanisms.

In addition to lacking a clear regulatory driver, technology or resource limitations continue to hinder routine network operations for NOy, mercury and organic carbon, although the NCore network should enhance NOy coverage. A multi-organizational effort coordinated by the NADP with EPA seed funding is initiating deployment of sustained dry speciated mercury measurements.

Vertical fields. Progress in separating satellite derived boundary layer ozone from free tropospheric and stratospheric components has been aided by use of multiple sensors and algorithm improvements. Continued advances are expected from studies based on the 2004 launching of NASA's Aura platform (http://aura.gsfc.nasa.gov/) with multiple trace gas capability, including glyoxal, a relatively stable VOC. The wealth of aerosol optical depth information from numerous satellite platforms has been applied to evaluating air quality models (references needed). LIDAR aboard CALIPSO offers some ability to resolve vertical gradients of aerosol driven light scattering. Vertical ozone profiles through Ozonesondes often are deployed during intensive field campaigns, however routine operations generally are conducted at remote locations through NOAA's global monitoring efforts (http://www.esrl.noaa.gov/gmd/ozwv/ozsondes/index.html). Aircraft derived trace gas profiles would provide an important component for model evaluation efforts.

Recommendations.

1. Complement the existing surface based networks with routine vertical gradient measurements of trace gases through aircraft platforms, sondes or other approaches.
2. Implement the NCore surface observation program and consider adding glyoxal measurements and expanding NOy monitoring.
3. Gradually expand coverage of surface based dry speciated mercury measurements.
4. Conduct periodic vertical profile dry speciated mercury measurements through aircraft noting the absence of satellite derived contributions to mercury characterization.

Dry Deposition.

Dry deposition characterization presents significant challenges as deposition is a function of a species chemical and physical properties, meteorology and surface attributes. Direct surface deposition measurements are complicated by these factors as well as suitability of surrogate surface substrates. Consequently, dry deposition is calculated as a function of ambient concentration and various metrological, surface and species specific properties. From a model evaluation perspective, dry deposition is the most difficult quantity to characterize in a traditional observation to prediction association. Consequently, improvement in characterization of surface types, near surface meteorology and concentration fields should improve dry deposition parameterizations. Because dry deposition velocities are difficult to parameterize and impact ambient fields significantly, some level of inverse dry deposition parameterization similar to inverse emissions modeling may offer practical near term improvements in modeling performance.

Role of Intensive Field Campaigns

Intensive field campaigns are critical tools for probing specific processes and often are the only sources of vertical profile and highly resolved chemical and temporal information. However, model evaluation often is a secondary objective of intensive studies which typically are focused on characterizing a specific process (e.g. chemical processing in clouds, inverse emissions inventory development, transoceanic fate and transport). Occasional, well conceived field campaigns focused on comprehensive model evaluation might account for the consequent impact an improved module imparts on a fully integrated modeling system.

Coordination with air program management planning. Model applications supporting regulatory assessments typically establish a current base year generally coincident with both the attainment status designation period and the most recent updated national emissions inventory. For example, the 2002 base year will serve as a basis for national level analyses over the next two or three years. The 2002 CMAQ platform incorporates the most recent major improvement of national emissions inventory, as well a newer generation CTM that integrates ozone, particulate matter and a variety of air toxics species. National level inventories usually follow three year cycles with a 2 - 4 year lag built in to acquire and synthesize data from States and local agencies. Attainment status for the annual $PM_{2.5}$ standard was based on 2001 - 2003 observations. A closer alignment with major field campaigns during that period (e.g., 2001 Eastern U.S. Supersites and 2004 ICARTT) would have elevated base case evaluation efforts, and potentially broaden the interest and perceived value of intensive studies.

Addressing spatial and temporal information gaps.

Air quality models are multifaceted integrators across various spatial scales (horizontally and vertically) and time periods. Consequently, model evaluations are strengthened by a richness of coverage across spatial and temporal frames, in addition to compositional variety. In general, our air quality networks include an abundance of surface based measurements, many of which are collected over 24 hour (chemical speciation networks) or even weekly (CASTNET) averaging periods. Model evaluations benefit strongly from added temporal and

vertical richness in data sets. Consequently, the value in adding aircraft and other vertical profiling programs is likely to provide great value relative to other needed observation enhancements. Greater leveraging of the myriad of satellite campaigns conceptually could be achieved by ground based and vertical profiling efforts designed to complement satellite systems. And, the proposed addition of future geosynchronous satellite missions measuring trace gases and aerosol properties focused on North America would add a near continuous stream of data greatly extending the current twice daily scans from polar orbiting satellite platforms.

Ground based enhancements in deploying continuous sulfate, carbon and nitrate aerosols, ammonia and nitric acid gases are obvious temporal gaps, given the current reliance on multi-hour collection requirements of filter and denuder based systems. From a horizontal scale perspective, most of the discussion on measurement needs is associated with regional (50 – 500 km) and urban (15- 50 km) spatial frames, with some attention to hemispheric transport scales through sentinel stations and satellites. The demand on models to address near field characterizations to support human exposure assessments, near roadway phenomena and urban residuals remaining after implementation of region-wide emission strategies will require attention.

Summary

Modern air quality models attempt to integrate numerous physical and chemical properties with varying degrees of interdependencies among model components. Consequently, data needs supporting model evaluation span a variety of meteorological, emissions and chemical fields. Model evaluation initially should address key meteorological and emissions input fields which service critical downstream chemical processing and removal processes. The model evaluation process would be strengthened by (1) enhancements in vertical gradient profiles for meteorological and air quality parameters, (2) improved surface network coverage of conserved tracer species (e.g., CO) and transformed end products such as total reactive nitrogen, NOy (Table 2). Recommendations include:

- Meteorology. Establish a centralized data repository and synthesis system for boundary layer profiler and aircraft data, and enhance the existing profiler network to enable routine construction of spatially and temporally variant PBL depths,
- Emissions. Conduct periodic focused emission measurement studies across different source sectors with periodic revisits to improve emission estimates and assess impact on emissions associated implementation of technology changes and emissions strategies,
- Boundary Conditions/transport. Add and maintain sentinel monitoring stations in key transport corridor inflow and outflow locations to enable evaluation of global scale models generating boundary value inputs for regional scale applications,
- Ambient fields – emissions precursors and tracers. Implement the existing NCore multiple pollutant trace gas strategy and extend coverage of CO measurements,
- Ambient fields – intermediate species. Complete testing and development of true, field deployable NO2 instrumentation. Increase formaldehyde measurement coverage to include representative rural areas in addition to current urban based network. Conduct periodic sampling in 1 or 2 urban areas for selected fast reacting and intermediate

species [radicals (hydroxyl, organic and hydroperoxy, nitrate), peroxides, and nitrous acid].

- Ambient fields – secondary species. Increase coverage of NOy measurements, particularly in rural environments; continuous aerosol speciation instruments and considering adding glyoxal measurements, or other appropriate indicator oftransformed VOC emissions.
- Vertical gradients. Through a combination of aircraft in-situ measurements and ground based in-situ sondes and remotes sensing instrumentation, establish routine collection of key meteorological and air quality parameters.
- Boundary layer column measurements – Establish geosynchronous satellite platforms for trace gases and aerosol properties to provide near continuous streams of space based observations.
- Intensive field campaigns – Design and implement periodic studies focused on comprehensive model evaluation information needs.

Table 2. Qualitative summary of key meteorological and air quality data sets for air quality model evaluation. {S – surface layer; VG – vertical gradient; BLCT – boundary layer column total}			
Component	**Relative Difficulty**	**Data Availability**	**Notes and exceptions**
Meteorological Data			
PBL heights	M	L	PBL heights dependent on vertical temperature and reflectivity profiles
Mixing processes (winds, dispersion factors)	M	H	
Clouds and radiation	H	M	
Air quality Data			
Conservative species (CO and EC)			
S	L	L	Based primarily on CO
VG	M	L	
BLCT	M	M	
Intermediate species (OH·, RO2·, HO2·, HCHO, HOOH, ROOH, HONO, NO3·)			
S	H	L	BLCT M scores only address NO_2, HCHO; M difficulty for NO2, HCHO
VG	H	L	
BLCT	M	M	
Transformed species (O3, NO3, SO4, Hg, Org-C, Light scattering)			
S	L	H	Hg and speciated Org-C low availability and high difficulty
VG	M	L	
BLCT	M	M	

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3.8 Strategies and Information Technology solutions

[this section is intended to discuss data access, delivery and interpretation issues {VIEWS, AQS, DataFed, AIRNOW, as well as note existence of various organizational efforts and strategies (IGACO, WMO/GAW, GEOSS) with themes consistent with this assessment]

Appendix 1: summary of Existing Networks

This appendix provides information on a wide variety of air monitoring networks. Major networks that are currently operating are emphasized; reference to other networks that have been discontinued, or that were only intended for a specific operating period, is also provided. The focus is on networks located in the U.S., but attention is also given to other North American, European and international efforts that contribute to U.S. assessments. The networks identified include:

-- Table 1. Major Routine Operating Air Monitoring Networks
- Table 1a. Summary of Networks for Inorganic Gases
- Table 1b. Summary of Networks for Organic Gases
- Table 1c. Summary of Networks for Particulate Matter (PM)
- Table 1d. Summary of Measurement Sites for Particulate Matter (PM2.5) Speciation

-- Table 2. Air Monitoring Networks/Campaigns for Non-Routine Special Intensive Studies

-- Table 3. Air Monitoring Networks for Climate Forcing, Transport, and Stratospheric Ozone

-- Table 4. Observation Systems Providing Vertical Profile Information

-- Table 5. National Routine Meteorological Monitoring Networks

-- Table 6. Satellite–Based Air Quality Observing Systems

-- Table 7. European Air Monitoring Networks

-- Table 8. Monitoring Networks for Persistent Organic Pollutants (POPs)

In all cases the network name, lead agency, number of monitoring sites, the year initiated, measurement parameters (primarily air pollutants and meteorological parameters), and the Internet address for information and/or data for the network are identified. The major routine monitoring networks are further detailed in terms of the number of sites measuring specific pollutants, i.e., inorganic, organic, particulates and particulate (PM2.5) species, as part of selected networks. Maps showing the approximate locations of monitoring sites for the major routine networks are also provided. Limited supplemental information is given with the non-routine special intensive studies and with the satellite observing systems.

Information in Tables 1 through 8 is the product of extensive Internet searches and information provided by knowledgeable representatives of the agencies responsible for the networks. In most cases, the information provided has been taken directly from the referenced Internet site. This is particularly true of supplemental information for the non-routine special intensive

studies and of maps for the major routine networks. Attribution of this information should be to those Internet websites.

The purpose of this section, in addition to providing a useful reference or starting point, has been to claim a basis for needed air monitoring network enhancements, whether they be for additional parameters, site locations in key rural gaps and source areas, or added vertical information. While Tables 1 through 8 provide only a limited factual synopsis of the air monitoring networks and data that may be available, they do provide a start for the more analytical process of identifying the value that is and is not provided by the networks. Ideally, the catalog of tables should form a basis for assessment, i.e., the redundancies, the gaps, and the effectiveness of networks in meeting intended objectives. Such an assessment sets the stage for subsequent recommendations, but implementation is likely to be beyond the scope of this report.

TABLE 1. MAJOR ROUTINE OPERATING AIR MONITORING NETWORKS[5]

Network	Lead Federal Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
State / Local / Federal Networks					
NCore[1] -- National Core Monitoring Network	EPA	75	2008	O3, NO/NO2/NOy, SO2, CO, PM2.5/PM10-2.5[2], PM2.5 speciation, NH3, HNO3, Surface Meteorology[3]	http://www.epa.gov/ttn/amtic/monstratdoc.html
SLAMS[1] -- State and Local Ambient Monitoring Stations	EPA	~3000	1978	O3, NOx/NO2, SO2, PM2.5/PM10, CO, Pb	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
STN -- PM2.5 Speciation Trends Network	EPA	300	1999	PM2.5, PM2.5 speciation, Major Ions, Metals	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm

PAMS -- Photochemical Assessment Monitoring Network	EPA	75	1994	O3, NOx/NOy, CO, Speciated VOCs, Carbonyls, Surface Meteorology & Upper Air	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
IMPROVE -- Interagency Monitoring of Protected Visual Environments	NPS	110 plus 67 protocol sites	1988	PM2.5/PM10, Major Ions, Metals, Light Extinction, Scattering Coefficient	http://vista.cira.colostate.edu/IMPROVE/
CASTNet -- Clean Air Status and Trends Network	EPA	80+	1987	O3, SO2, Major Ions, Calculated Dry Deposition, Wet Deposition, Total Deposition for Sulfur/Nitrogen, Surface Meteorology	http://www.epa.gov/castnet/
GPMP -- Gaseous Pollutant Monitoring Network	NPS	33	1987	O3, NOx/NO/NO2, SO2, CO, Surface Meteorology, (plus enhanced monitoring of CO, NO, NOx, NOy, and SO2 plus canister samples for VOC at three sites)	http://www2.nature.nps.gov/air/Monitoring/network.cfm#data
POMS -- Portable Ozone Monitoring Stations	NPS	14	2002	O3, surface meteorology, with CASTNet-protocol filter pack (optional) sulfate, nitrate, ammonium, nitric acid, sulfur dioxide	http://www2.nature.nps.gov/air/studies/portO3.cfm
Passive Ozone Sampler Monitoring Program	NPS	43	1995	O3 dose (weekly)	http://www2.nature.nps.gov/air/Studies/Passives.cfm
NADP/NTN -- National Atmospheric Deposition Program / National Trends Network	USGS	200+	1978	Major Ions from precipitation chemistry	http://nadp.sws.uiuc.edu/
NADP/MDN -- National Atmospheric Deposition Program / Mercury Deposition Network	None	90+	1996	Mercury from precipitation chemistry	http://nadp.sws.uiuc.edu/mdn/
AIRMoN -- National Atmospheric Deposition Program / Atmospheric Integrated Research Monitoring Network	NOAA	8	1984	Major Ions from precipitation chemistry	http://nadp.sws.uiuc.edu/AIRMoN/
IADN -- Integrated Atmospheric Deposition Network	EPA	20	1990	PAHs, PCBs, and organochlorine compounds are measured in air and precipitation samples	http://www.epa.gov/glnpo/monitoring/air/
NAPS -- National Air Pollution Surveillance Network	Canada	152+	1969	SO2, CO, O3, NO, NO2, NOx, VOCs, SVOCs, PM10, PM2.5, TSP, metals	http://www.etcentre.org/NAPS/
CAPMoN -- Canadian Air and Precipitation Monitoring Network	Canada	29	2002	O3, NO, NO_2, NO_y, PAN, NH_3, $PM_{2.5}$, PM_{10} and coarse fraction mass, PM2.5 speciation, major ions for particles and trace gases, precipitation chemistry for major ions	http://www.msc.ec.gc.ca/capmon/index_e.cfm
Mexican Metropolitan Air Quality Network	Mexico	93	???	O3, NOx, CO, SO2, PM10, TSP	See CEC, 1997[7]

TABLE 1. MAJOR ROUTINE OPERATING AIR MONITORING NETWORKS (continued)

Air Toxics Monitoring Networks					
NATTS -- National Air Toxics Trends Stations	EPA	23	2005	VOCs, Carbonyls, PM10 metals[4], Hg	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
State/Local Air Toxics Monitoring	EPA	250+	1987	VOCs, Carbonyls, PM10 metals[4], Hg	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
NDAMN -- National Dioxin Air Monitoring Network	EPA	34	1998 - 2005	CDDs, CDFs, dioxin-like PCBs	http://cfpub2.epa.gov/ncea/cfm/recordisplay.cfm?deid=22423
Tribal Monitoring Networks					
Tribal Monitoring[6]	EPA	120+	1995	O3, NOx/NO2, SO2, PM2.5/PM10, CO, Pb	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
Industry / Research Networks					
New Source Permit Monitoring	None	variable	variable	O3, NOx/NO2, SO2, PM2.5/PM10, CO, Pb	Contact specific industrial facilities

HRM Network -- Houston Regional Monitoring Network	None	9	1980	O3, NOx, PM2.5/PM10, CO, SO2, Pb, VOCs, Surface Meteorology	http://hrm.radian.com/houston/how/index.htm
ARIES / SEARCH -- Aerosol Research Inhalation Epidemiology Study / SouthEastern Aerosol Research and Characterization Study experiment	None	8	1992	O3, NO/NO2/NOy, SO2, CO, PM2.5/PM10, PM2.5 speciation, Major Ions, NH3, HNO3, scattering coefficient, Surface Meteorology	http://www.atmospheric-research.com/studies/SEARCH/index.html
SOS - SERON -- Southern Oxidant Study - Southeastern Regional Oxidant Networks	EPA	~40	1990	O3, NO, NOy, VOCs, CO, Surface Meteorology	http://www.ncsu.edu/sos/pubs/sos3/State_of_SOS_3.pdf
National/Global Radiation Networks					
RadNet -- formerly Environmental Radiation Ambient Monitoring System (ERAMS)	EPA	200+	1973	Radionuclides and radiation	http://www.epa.gov/enviro/html/erams/
SASP -- Surface Air Sampling Program	DHS	41	1963	^{89}Sr, ^{90}Sr, naturally occurring radionuclides, ^{7}Be, ^{210}Pb	http://www.eh.doe.gov/ohre/new/findingaids/radioactive/doe/2.html
NEWNET -- Neighborhood Environmental Watch Network	DOE	26	1993	Ionizing gamma radiation, Surface Meteorology	http://newnet.lanl.gov/stations.asp
CTBT -- Comprehensive Nuclear Test Ban Treaty	DOE	80	1996	Radionuclides and noble gases	http://www.clw.org/archive/coalition/briefv3n14.htm
Other Networks					
UV Index -- EPA Sunwise Program	EPA	~50 U.S. cities	2002	Calculated UV radiation index	http://www.epa.gov/sunwise/uvindex.html
UV Net -- Ultraviolet Monitoring Program	EPA	21	2002	Ultraviolet solar radiation (UV-B and UV-A bands)	http://www.epa.gov/uvnet/access.html
UV-B Monitoring and Research Program	USDA	35	1992	Ultraviolet-B radiation	http://uvb.nrel.colostate.edu/UVB/jsp/uvb_climate_network.jsp
SURFRAD -- Surface Radiation Budget Network	NOAA	7	1993	solar and infrared radiation, direct and diffuse solar radiation, photosynthetically active radiation, UVB, spectral solar, and meteorological parameters	http://www.srrb.noaa.gov/surfrad/index.html
PRIMENet -- Park Research & Intensive Monitoring of Ecosystems NETwork	NPS	14	1997	ozone, wet and dry deposition, visibility, surface meteorology, and ultraviolet radiation	http://www.forestry.umt.edu/research/MFCES/programs/primenet/
BioWatch	No details				

Footnotes:

1. NCore is a network proposed to replace NAMS, as a component of SLAMS; NAMS are currently designated as national trends sites.

2. PM10-2.5 -- proposed new NAAQS.

3. Surface Meteorology includes wind direction and speed, temperature, precipitation, relative humidity, solar radiation (PAMS only).

4. PM10 metals may include arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, and others.

5. Some networks listed separately may also serve as subcomponents of other larger listed networks; as a result, some double counting of the number of individual monitors is likely.

6. The number of sites indicated for tribal monitoring is actually the number of monitors, rather than sites. The number of sites with multiple monitors is probably less than 80.

7. CEC, 1997. Background Document on Air Quality Data Compatibility. Prepared for the North American Monitoring and Modeling Project of the CEC, August 1997

TABLE 1a. SUMMARY OF NETWORKS FOR INORGANIC GASES

Numbers of Measurement Sites for Each Inorganic Gas

Network	Total Number of Sites	Ozone (O3)	Nitrogen Oxides (NOx)	Nitrogen Oxide (NO)	Nitrogen Dioxide (NO2)	Total Reactive Nitrogen (NOy)	Ammonia (NH3)	Nitric Acid (HNO3)	Sulfur Dioxide (SO2)	Carbon Monoxide (CO)	Location of Information and/or Data
State / Local / Federal Networks											
NCore[1,6]	75	75		75	75	75	75	75	75	75	http://www.epa.gov/ttn/amtic/monstratdoc.html
SLAMS[2]	~3000	1783	306	373	613	75	29		819	714	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
PAMS[2]	75	50	60	61	54	3				1	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
CASTNet[3,7]	80+	88						88	88		http://www.epa.gov/castnet/
GPMP[2]	33	35							4	1	http://www2.nature.nps.gov/air/Monitoring/network.cfm#data
Tribal Monitoring Networks											
Tribal[2]	120+	21	6	10	13	4	1		16	6	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
Industry Networks											
New Source Permit[2]	variable	8	18	20	24				66	8	Contact specific industrial facilities
ARIES/SEARCH[4]	8	8	8	8	8	8	2	8	8	8	http://www.atmospheric-research.com/studies/SEARCH/index.html
HRM Network[5]	9	9			9				9	9	http://hrm.radian.com/houston/how/index.htm

Footnotes:

1. NCore is a network proposed to replace NAMS, as a component of SLAMS; NAMS are designated as national trends sites.

2. Counts of sites for which selected inorganic gases are measured are based on a search of air quality measurements in AQS that was made on 04/19/06. Monitor type, pollutant or "parameter" code, and the last sampling date for a given monitoring site were the primary search factors considered. Last sampling dates encompassed 2004 to the present. Parameter codes unique to each pollutant were chosen. The following monitor types were selected for inclusion with the indicated types of networks:
   a. SLAMS network includes: NAMS, SLAMS, other, non-regulatory, special purpose, and unknown monitoring types
   b. PAMS network includes: PAMS and unofficial PAMS monitoring types
   c. GPMP network includes: Non-EPA federal monitoring type
   d. Tribal network includes: Tribal monitors type; also, the number of sites indicated for tribal monitoring is actually the number of monitors, rather than sites. The number of sites with multiple monitors is probably less than 80.
   e. New Source Permit network includes: Industrial type.

3. Counts of sites for which selected inorganic gases are measured are based on a "Quick Report" for 2004 from the CASTNet website made on 04/19/06; measurements of pollutants, other than O3, are based on Filter Pack providing weekly integrated averages.

4. Counts of sites for which selected inorganic gases are measured are based on information from the SEARCH website taken on 04/19/06.

5. Counts of sites for which selected inorganic gases are measured are based on information from the HRM website taken on 04/19/06.

6. Monitoring for NO2, NH3 and HNO3 under NCore is pending the availability of suitable methods.

7. HNO3 values under CASTNet include some volatile fraction from particle nitrates.

TABLE 1b. SUMMARY OF NETWORKS FOR ORGANIC GASES

Numbers of Measurement Sites for Each Organic Gas

Network	Total Number of Sites	VOCs[1,2]	Carbonyls[3]-- formaldehyde	Carbonyls[3]-- acetaldehyde	Carbonyls[3]-- acetone	Location of Data
State / Local / Federal Networks						
PAMS[4]	75	96	32	31	22	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
Air Toxics Monitoring Networks						
NATTS[5]	23	21	18	18	14	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
State/Local Toxics Monitoring[2,4]	250+	141	240	242	243	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
Local / Community Grants[7]						http://www.epa.gov/ttn/amtic/local.html
Industry Networks						
HRM Network[6]	9	9				http://hrm.radian.com/houston/how/index.htm

Footnotes:

1. PAMS VOCs include 55 hydrocarbon compounds through methods described in Technical Assistance Document.

2. Air toxics VOCs include ~55 hydrocarbon compounds through method TO-15.

3. Carbonyls include 3 compounds through method TO11A.

4. Counts of sites for which selected organic gases are measured are based on a search of air quality measurements in AQS that was made on 04/19/06. Monitor type, pollutant or "parameter" code, and the last sampling date for a given monitoring site were the primary search factors considered. Last sampling dates encompassed 2004 to the present. Parameter codes unique to each pollutant were chosen. The following monitor types were selected for inclusion with the indicated types of networks:
PAMS network includes: PAMS and unofficial PAMS monitoring types
State/local Toxics Monitoring networks include: NAMS, SLAMS, other, non-regulatory, special purpose, and unknown monitoring types.

5. Counts of sites for which selected organic gases are measured are based on a search of air quality measurements in AQS that was made on 04/26/09 for the year 2005. NATTS also measures PM10 metals, including arsenic, beryllium, cadmium, chromium, lead, manganese, and nickel.

6. Counts of sites for which selected organic gases are measured are based on information from the HRM website taken on 04/19/06.

7. Beginning in FY 2004, approximately 15 special study grants per year, under Section 103 authority, are to awarded to State/local agencies and to tribes.

TABLE 1c. SUMMARY OF NETWORKS FOR PARTICULATE MATTER (PM)

Numbers of Measurement Sites for Each Measurement of PM

Network	Total Number of Sites	PM2.5 filter	PM2.5 continuous[2]	PM10	Location of Information and/or Data
State / Local / Federal Networks					
NCore[1]	75	75	75		N/A
SLAMS[1,3]	~3000	1573	647	1592	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
STN[3]	54	54			http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
IMPROVE	110 plus 67 protocol sites	167			http://vista.cira.colostate.edu/improve/
Tribal Monitoring Networks					
Tribal[3]	120+	51	12	41	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
Industry Networks					
New Source Permit[3]	variable	1	1	120	Contact specific industrial facilities
ARIES/SEARCH[4]	8	8	8	8	http://www.atmospheric-research.com/studies/SEARCH/index.html
HRM Network[5]	9	9		9	http://hrm.radian.com/houston/how/index.htm

Footnotes:

1. NCore is a network proposed to replace NAMS, as a component of SLAMS; NAMS are designated as national trends sites.

2. Several methods are included (TEOM, light scattering, BAMS)

3. Counts of sites for PM are based on a search of air quality measurements in AQS that was made on 04/19/06. Monitor type, pollutant or "parameter" code, and the last sampling date for a given monitoring site were the primary search factors considered. Last sampling dates encompassed 2004 to the present. Parameter codes unique to each pollutant were chosen. The following monitor types were selected for inclusion with the indicated types of networks:
SLAMS network includes: NAMS, SLAMS, other, non-regulatory, special purpose, unknown, SLAMS speciation monitoring types
STN network includes: Trends speciation types
Tribal network includes: Tribal monitors type. Also, the number of sites indicated for tribal monitoring is actually the number of monitors, rather than sites. The number of sites with multiple monitors is probably less than 80.
New Source Permit network includes: Industrial type.

4. Counts of sites for which selected inorganic gases are measured are based on information from SEARCH website taken 04/19/06.

5. Counts of sites for which selected inorganic gases are measured are based on information from the HRM website taken on 04/19/06.

TABLE 1d.
SUMMARY OF MEASUREMENT SITES FOR PARTICULATE MATTER (PM2.5) SPECIATION[0]

Numbers of Measurement Sites for Each PM Species

Network	Total Number of Sites	Major Ions (SO4,NO3,NH4)	OC	EC	Trace Elements[9]	Sampling Frequency	Location of Information and/or Data
State / Local / Federal Networks							
NCore[1]	–	–	–	–	–		http://www.epa.gov/ttn/amtic/monstratdoc.html
SLAMS – EPA[2,5]	~150	207	207	207	207		http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
STN --EPA[3,5]	54	54	54	54	54	3-day schedule 24-hr average	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
IMPROVE -- Class I[8]	110	110	110	110	110		http://vista.cira.colostate.edu/improve/
IMPROVE -- Protocol[4,8]	67	67	67	67	67		http://vista.cira.colostate.edu/improve/
CASTNet[6]	80+	88				weekly average	http://www.epa.gov/castnet/
Industry Networks							
ARIES/SEARCH[7]	8	8	8	8	8		http://www.atmospheric-research.com/studies/SEARCH/index.html

0. Methods Discussion (Rich).

1. NCore is a network proposed to replace NAMS, as a component of SLAMS; NAMS are designated as national trends sites. To avoid double counting, the NCore sites are incorporated in STN and SLAMS totals.

2. Based on EPA samplers; does not include IMPROVE protocol.

3. Based in National Park Class 1 areas; also includes 2 sites.

4. Includes ~10 CASTNET located sites, and other RPO and EPA -- SLAMS funded sites.

5. Counts of sites for which selected PM species are measured are based on a search of air quality measurements in AQS that was made on 04/19/06. Monitor type, pollutant or "parameter" code, and the last sampling date for a given monitoring site were the primary search factors considered. Last sampling dates encompassed 2004 to the present. Parameter codes unique to each pollutant were chosen. The following monitor types were selected for inclusion with the indicated types of networks:

SLAMS -- EPA network includes: SLAMS speciation types
STN -- EPA network includes: Trends speciation, PAMS, and unofficial PAMS monitoring types.

6. Counts of sites for which selected PM species are measured are based on a "Quick Report" for 2004 from the CASTNet website made on 04/19/06. Measurements at CASTNet sites utilize an open inlet (all particle sizes) and Filter Pack providing weekly integrated averages for sulfate and total nitrate (particles and nitric acid).

7. Counts of sites for which selected PM species are measured are based on information from the SEARCH website taken on 04/19/06.

8. IMPROVE does not report NH4 due to concerns regarding NH3 offgases from filters.

9. Elements include Na to Pb on the periodic table measured through typical XRF scans and other analysis techniques. Major differences between IMPROVE and EPA networks are analysis respectively of 24 versus 48 elements; differences in elements considered are currently being reassessed since many are rarely detected. A listing of elements is provided in the following table:

XRF Species	Species Name	XRF Species Reported in IMPROVE Databases	XRF Species Reported in STN Databases
Na	Sodium	X	X
Mg	Magnesium	X	X
Al	Aluminum	X	X
Si	Silicon	X	X
P	Phosphorus	X	X
S	Sulfur	X	X
Cl	Chlorine	X	X
K	Potassium	X	X
Ca	Calcium	X	X
Sc	Scandium		X
Ti	Titanium	X	X
V	Vanadium	X	X
Cr	Chromium	X	X
Mn	Manganese	X	X
Fe	Iron	X	X
Co	Cobalt		X
Ni	Nickel	X	X
Cu	Copper	X	X
Zn	Zinc	X	X
Ga	Gallium		X
As	Arsenic	X	X
Se	Selenium	X	X
Br	Bromine	X	X
Rb	Rubidium	X	X
Sr	Strontium	X	X
Y	Yttrium		X
Zr	Zirconium	X	X
Nb	Niobium		X
Mo	Molybdenum		X
Ag	Silver		X
Cd	Cadmium		X
In	Indium		X
Sn	Tin		X
Sb	Antimony		X
Cs	Cesium		X
Ba	Barium		X
La	Lanthanum		X
Hf	Hafnium		X
Ta	Tantalum		X
W	Tungsten		X
Ir	Iridium		X
Au	Gold		X
Hg	Mercury		X
Pb	Lead	X	X
Ce	Cerium		X
Sm	Samarium		X
Eu	Europium		X
Tb	Terbium		X

TABLE 2. AIR MONITORING NETWORKS / CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES[3,4]

Network	Lead Agency[1]	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data	Notes
Texas Air Quality Study II (2005 - 2006)	Texas	17	2006	O3, NOx, NOy, SO2, Haze, Visibility, CO, VOC, Solar Radiation, Surface Meteorology, Upper Air	http://www.utexas.edu/research/ceer/texaqsII/PDF/12-12-04_Projected_Surface Sites_tbl.pdf	Researchers from universities, state and federal agencies, private industry, and local governments are joining forces to conduct a major field study to address air quality issues in the eastern half of Texas. The study, planned for a period extending from April 2005 through October 2006, will examine regional ozone formation, transport of ozone and ozone precursors, meteorological and chemical modeling, issues related to ozone formation by highly reactive emissions, and particulate matter formation. It is anticipated that the information from the study will be the scientific basis used for developing State Implementation Plans (SIPs) for ozone (with concentrations averaged over 8 hours), regional haze, and, if necessary, for fine particulate matter (particulate matter less than 2.5 microns in diameter, $PM_{2.5}$
2006 Texas Air Quality Study/ Gulf of Mexico Atmospheric Composition and Climate Study (TexAQS/GoMACCS)	NOAA	1 ship, 2 aircraft	2006	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/2006/	For TexAQS 2006, the NOAA air quality component will investigate, through airborne and sea-based measurements, the sources and processes that are responsible for photochemical pollution and regional haze during the summertime in Texas. The focus of the study will be the transport of ozone and ozone precursors within the state and the impact of the long-range transport of ozone or its precursors.
Intercontinental Chemical Transport Experiment - North America (INTEX-B) -- Intercontinental Transport and Chemical Transformation (ITCT/IGAC)	NOAA	3 aircraft	2006	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude -- NOAA aircraft	http://cloud1.arc.nasa.gov/intex-b/	The export of air pollutants from urban to regional and global environments is a major concern because of wide-ranging potential consequences for human health, cultivated and natural ecosystems, visibility degradation, weather modification, changes in radiative forcing, and tropospheric oxidizing capacity. During the spring of 2006 a highly integrated atmospheric field experiment was performed over and around North America. The Megacity Initiative: Local and Global Research Observations (MILAGRO), http://www.eol.ucar.edu/projects/milagro/ , resulted through a highly coordinated collaboration between NSF (through MIRAGE-Mex), DOE (through MAX-Mex), NASA (through INTEX-B) and a variety of research institution in the U.S. and Mexico and involved ground and air borne activities centered on Mexico City, Mexico during March 2006. MILAGRO goals were greatly facilitated and enhanced by a number of concurrent and coordinated national and international field campaigns and global satellite observations. After MILAGRO, NASA continued investigating this issue, this time focusing on the influence of Asian pollutants on North America, through a second airborne field element of INTEX-B in collaboration with NSF and NCAR. The integrated goals of MILAGRO and INTEX are: -To study the extent, persistence, and transformation of Mexico City pollution plumes; -To relate atmospheric composition to sources and sinks; -To quantify radiative properties and effects of aerosols, clouds, water vapor & surfaces; -To map anthopogenic and biogenic emissions; -To characterize transport and evolution of Asian pollution to North America and beyond and determine implications for regional air quality and climate; -To achieve science-based validation of satellite observations of troposheric composition

TABLE 2. AIR MONITORING NETWORKS / CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

Intercontinental Chemical Transport Experiment - North America (INTEX-NA) -- Intercontinental Transport and Chemical Transformation (ITCT/IGAC)	NOAA	aircraft, sondes, satellites	2004	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude -- NOAA aircraft	http://cloud1.arc.nasa.gov/intex-na/desc.html	INTEX-NA is an integrated atmospheric field experiment performed over and around North America. It seeks to understand the transport and transformation of gases and aerosols on transcontinental/intercontinental scales and their impact on air quality and climate. A particular focus in this study is to quantify and characterize the inflow and outflow of pollution over North America. The main constituents of interest are ozone and precursors, aerosols and precursors, and the long-lived greenhouse gases. INTEX-NA is part of a larger international ITCT (Intercontinental Transport and Chemical Transformation) initiative. INTEX-NA goals are greatly facilitated and enhanced by a number of concurrent and coordinated national and international field campaigns and satellite observations. Synthesis of the ensemble of observations from surface, airborne, and space platforms, with the help of a hierarchy of models is an important goal of INTEX-NA.
New England Air Quality Study (NEAQS) -- Intercontinental Transport and Chemical Transformation (ITCT) 2004	NOAA	4 site, 1 ship, 2 aircraft, profiler network	2004	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/2004/	NOAA continues a joint regional air quality and climate change study combining elements of the previous NEAQS study and the Intercontinental Transport and Chemical Transformation (ITCT) research activity to focus on air quality along the Eastern Seaboard and transport of North American emissions into the North Atlantic. The major NOAA assets (the two aircraft and the ship) are deployed in a manner that supports the objectives of both components.
East Tennessee Ozone Study (ETOS)	NOAA	15+	2003	O3, Surface Meteorology	http://www.atdd.noaa.gov/etos.htm	ETOS 2003 developed a regional ozone database to include both mean hourly averages and hourly histograms of individual measurement readings. The 2003 study period (based on scoping studies 1999 - 2002) provides a regional view to supplement Tennessee's regulatory network and serves as a demonstration and evaluation/validation database for various operational and developmental air quality forecast model components. The full scope of ETOS 2000 is continuously under planning and review, and is refined each year using the previous year's analysis and experience to focus on particular issues within the East Tennessee region.
Texas Air Quality Study (TexAQS) 2000	Texas	~20	2002	O3, NOx, PM2.5/PM10, CO, SO2, VOCs, Surface Meteorology	http://www.utexas.edu/research/ceer/texaqs/visitors/about.html	The study is designed to improve understanding of the factors that control the formation and transport of air pollutants along the Gulf Coast of southeastern Texas. Six weeks of intensive sampling, including measurements of gaseous, particulate, and hazardous air pollutants, are made at approximately 20 ground stations, located throughout the eastern half of the state. Experts in meteorology, atmospheric chemistry, and other areas of science study the formation, composition, and day-night cycles of ozone and particulate matter, as well as how these pollutants are affected by weather.
Texas Air Quality Study (TexAQS) 2000 Field Campaign	NOAA	2 aircraft	2002	O3, CO, CO2, SO2, NO, NO2, NOy, PAN, HNO3, NH3, VOCs, Solar Radiation, Meteorological Parameters, aerosols	http://www.utexas.edu/research/ceer/texaqs/visitors/about.html	Additional sampling in TexAQS 2000 is carried out with specially equipped aircraft that can detect air pollutants very quickly, at very low concentrations.

TABLE 2. AIR MONITORING NETWORKS / CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

Bay Region Atmospheric Chemistry Experiment (BRACE)	NOAA	1 aircraft	2002	NO3, NH4, O3, SO2, NOx, CO, trace metals, particulates	http://www.dep.state.fl.us/secretary/news/2002/02-039.htm	The Florida Department of Environmental Protection (DEP), with the support of a team of federal, state, local, university and private scientists (including NOAA) conducted a month-long series of intensive studies to determine the level of influence of nitrogen deposited into Tampa Bay from local and regional sources of air pollutants on water quality. During the Bay Region Atmospheric Chemistry Experiment (BRACE), NOAA operated a research aircraft over the Tampa Bay region to collect air quality measurements of the many atmospheric forms of nitrogen and related pollutants that may potentially influence the water quality of Tampa Bay.
New England Air Quality Study (NEAQS) 2002 -- AIRMAP	NOAA	4	2002	O3, NOx, NOy, SO2, CO, VOCs, PM2.5, Precipitation Chemistry, Surface Meteorology	http://airmap.unh.edu/data/	AIRMAP is a research program focused on atmospheric chemical and physical observations in rural to semi-remote areas of New Hampshire with the goal of understanding inter-relationships in regional air quality, meteorology, and climatic phenomena. Research goals are to: (1) document and analyze current trends in the regional air quality of New England which is affected by transport from upwind regions of the U.S. and Canada and by local emission sources; (2) document and analyze current and past (the last 100 years) synoptic-to-local meteorological patterns, features, and extreme events in New England; and (3) numerically simulate the coupled evolution of atmospheric transport and chemistry in New England using various modeling tools.
New England Air Quality Study (NEAQS) 2002	NOAA	1 ship, 2 aircraft	2002	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/NEAQS/	The NOAA component of this multi-institutional effort addresses the analysis of existing climate data, and the development of new air quality monitoring programs. A background of information is to be developed that addresses New England's changing climate and air quality so as to improve understanding of the relationship between air quality and weather and determine the causes of climate change in New England
Intercontinental Transport and Chemical Transformation (ITCT) 2002 Activities	NOAA	1 site, 1 aircraft	2002	CO2, CO, CH4, SO2, O3, SF6, N2O, CFCs, Aerosols, Solar Radiation, Surface Meteorology & Upper Air -- surface. O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air -- aircraft	http://esrl.noaa.gov/csd/ITCT/2k2/	This field program, scheduled for spring 2002 to investigate the composition of air masses along the Pacific coast of North America, is part of the Intercontinental Transport and Chemical Transformation (ITCT) research activity of the International Global Atmospheric Chemistry Program (IGAC) Program. Goals of this field study are to: characterize the chemical composition of the air masses coming ashore at the West Coast; explore the composition of these air masses as they are transported inland; and investigate the alteration in composition associated with the addition of emissions from U.S. West Coast sources. The NOAA WP-3D aircraft is to deploy a wide array of instrumentation for the in situ measurement of gaseous and aerosol parameters plus radiation and remote aerosol sensing by LIDAR. The Trinidad Head baseline observatory characterizes chemical composition of marine boundary layer at the U.S. West Coast and provides linkage between composition measurements and radiative properties of the aerosols. The NOAA ETL Laboratory network of 915-MHz radar wind profilers that are deployed in California provide additional meteorological information.

TABLE 2. AIR MONITORING NETWORKS / CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

TRAnsport and Chemical Evolution over the Pacific (TRACE-P)	NASA	2 aircraft	2001 (2 months)	O3, NO, NO2, N2O, CH4, SO2, NH3, CO, CO2, aerosols, PAN, HNO3, aldehydes, peroxides, speciated hydrocarbons, other pollutants, meteorological parameters	http://www-gte.larc.nasa.gov/gte_fld.htm#TRACE	TRACE-P is part of a series of aircraft missions aimed at better understanding of global tropospheric chemistry, and more specifically in this case, the effects of outflow from the Asian continent on the composition of the global atmosphere. Objectives are to determine: (1) pathways for outflow of chemically and radiatively important gases and aerosols, and their precursors, from eastern Asia to the western Pacific; and (2) the chemical evolution of the Asian outflow over the western Pacific, and the ensemble of processes that control this evolution. Approximately 20 aircraft measurement flights involving horizontal and vertical profiles for a total of over 300 hours were supported by surface based measurements and soundings.
Aerosol Characterization Experiments - Asia (ACE-Asia)	NSF	sites, ships, aircraft, satellites	2001 (spring)	aerosol chemical, physical, and radiative properties and radiative fluxes, meteorological parameters	http://saga.pmel.noaa.gov/Field/aceasia/ACEAsiaDescription.html	The Aerosol Characterization Experiments (ACE) are designed to increase understanding of how atmospheric aerosol particles affect the Earth's climate system. ACE-Asia took place during the spring of 2001 off the coast of China, Japan and Korea which includes many types of aerosol particles of widely varying composition and size. These particles include those emitted by human activities and industrial sources, as well as wind-blown dust. Data from ACE-Asia is improving understanding of how atmospheric aerosols influence the chemical and radiative properties of the Earth's atmosphere.
Central California Ozone Study (CCOS)[2]	California	100+ sites, 6 aircraft, profilers, sondes	2000	O3, VOC, NOx, NO, NOy, CO, PM10, PM2.5, solar radiation, surface meteorology, upper air	http://www.bayareamonitor.org/may00/air3.html	For the summer season, this study collected meteorological and air quality data for the central section of California in 2000. Planes and weather balloons collected data at ground level and aloft. The data collected is used to improve the understanding of the role of meteorology on the formation and behavior of air pollutants and their precursors and emission sources and patterns. The information gathered will be used to develop an improved modeling system that will be used in preparing plans to attain the new federal 8-hour ozone standard, as well as to update the Clean Air Plan to attain the state ozone standard.
California Regional Particulate Air Quality Study (CRPAQS)[2]	California	~60	1999 to 2001	PM2.5, PM10, nephelometer, with some sites adding SO4/NO3, OC/EC, NO2, NOy, PAN, SO2, surface meteorology	http://www.narsto.org/section.src?SID=9	The California Regional PM10/PM2.5 Air Quality Study is a comprehensive public/private sector collaborative program to provide an improved understanding of particulate matter and visibility in central California. It is intended to evaluate both the national and State air quality standards for PM10 and PM2.5. The field programs consisted of 14 months of monitoring throughout the San Joaquin Valley (SJV) and surrounding regions, as well as intensive monitoring during summer, fall, and winter seasonal periods.
Southern Oxidant Study (SOS) 1999 Field Campaign -- Nashville	NOAA	3 sites, 4 aircraft	1999	O3, NO, NO2, NOy, VOCs, aerosols, Surface Meteorology & Upper Air (profiler), ozonesonde -- surface O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude -- aircraft	http://esrl.noaa.gov/csd/SOS99/	The Southern Oxidants Study (SOS), in collaboration with other organizations and programs, conducted this major Field Campaign during June/July 1999. The Nashville/Middle Tennessee region measurements focused on an improved understanding of the processes that control the formation and distribution of fine particles and ozone. Three study themes were: Local vs. regional contrasts, Ozone and PM formation in plumes, and diurnal cycle in chemistry and meteorology. These themes were addressed through a series of coordinated measurements involving instrumented aircraft and a ground-based network of chemistry and meteorological measurements.

TABLE 2. AIR MONITORING NETWORKS / CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

PM Supersite Program	EPA	2 Phase I Sites 7 Phase II Sites	1999	Measurement may include: PM2.5, PM10, TSP, SO4, NO3, EC, OC, light absorption & extinction, O3, CO , NOx, NO, NO2, NOy, HNO3, NH3, VOCs, Carbonyls, PAH, major ions and elements, surface and upper air meteorology	http://www.epa.gov/ttn/amtic/supersites.html	In response to Executive and Congressional mandates and recommendations from the National Research Council a "Supersites Conceptual Plan" was developed and implemented. Atlanta and Fresno were selected as initial Phase I sites and as a result of a competitive process Baltimore, Fresno, Houston, Los Angeles, New York, Pittsburgh, and St. Louis were selected for Phase II. Goals generally were to characterize particulate matter, support health effects and exposure research, and conduct methods testing. Extensive monitoring, data analysis, and publication continued to 2005 with the preparation of a Final Report for each city.
Big Bend Regional Aerosol and Visibility Observational (BRAVO) Study	NPS/EPA	38 fixed, 6 tracer sites	1999	SO2, SO4, PM2.5, NO3, NH4, major ions and elements, nephelometer, transmissometer, meteorological parameters & upper air, PFC tracer	http://www.dri.edu/Home/Features/text/BRAVO.htm	The BRAVO study was conducted for four months during 1999 with the primary objective of identifying the causes of haze in the Big Bend National Park located in West Texas. This very large, collaborative study enlisted numerous participants with sponsorship from federal/State agencies, private industry, and research organizations. The BRAVO study utilized data from a 38-site network to characterize spatial and temporal aerosol patterns in the atmosphere. In addition, upper-air measurements and extensive optical measurements of light scattering and absorption were made. Because monitoring and source characterization activities were conducted only in the United States, the study design included additional monitoring and tracer studies along the U.S./Mexican border.
Indian Ocean Experiment (INDOEX)	UCSD	6 sites, 2 ships, 5 aircraft, satellites	1999 (4 months)	O3, NO, NO2, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, trace gases, aerosols, meteorological parameters & upper air	http://www-indoex.ucsd.edu/	The Indian Ocean Experiment (INDOEX) addresses questions of climate change through collection of in-situ data on the regional cooling effect of sulfate and other aerosols. The project's goal is to study natural and anthropogenic climate forcing by aerosols and feedbacks on regional and global climate. INDOEX field studies occur where pristine air masses from the southern Indian Ocean including Antarctica and not-so-clean air from the Indian subcontinent meet over the tropical Indian Ocean to provide a unique natural laboratory for studying aerosols. Scientists collect data from the water surface through the lower stratosphere, on the aerosol composition, reactive atmospheric gases, solar radiation fluxes, wind and water vapor distribution. To this end, investigators use multiple aircraft, ships and island stations over the Arabian Sea and the Indian Ocean.
Eulerian Model Evaluation Field Study (EMEFS)	Canada	~135	1998	O3, NO2, SO2, NH3, HNO3, major ions,	http://www.msc-smc.ec.gc.ca/natchem/particles/n_emefs_e.html	Under EMEFS, air and precipitation chemistry data were collected daily for two years over much of the eastern United States and Canada to provide data for assessing the performance of acid deposition and other regional scale models.
NARSTO-Northeast 1995	Multiple	559	1995	O3, NO, NOx	http://www.narsto.org/section.src?SID=9	Measurements were made during the NARSTO-Northeast 1995 intensive field campaign during the period May through September. One-hour average O3, NO, and NOX measurement results are reported for ground surface monitoring stations operated by various agencies including EPA AIRS, CASTNet, ESE, Harvard University, NYSEG, PEPCO, and the University of Maryland.

TABLE 2. AIR MONITORING NETWORKS / CAMPAIGNS FOR NON-ROUTINE SPECIAL INTENSIVE STUDIES (continued)

SOS Nashville/Middle Tennessee Ozone Study	TVA	116	1994-1995	O3, SO2, NO, NOy, and CO, VOC, Surface Meteorology, rawinsonde and ozonesonde releases, and a radar profiler/radar acoustic sounding system. -- surface Airborne ozone and aerosol lidar – aircraft	http://www.ncsu.edu/sos/pubs/sos2/State_of_SOS_2.pdf	This ozone-focused field study was carried out in the 11-state region surrounding Nashville/Middle Tennessee, beginning with a 3-week exploratory study during the summer of 1994 and culminating in a six-week field measurement campaign June/July 1995. Measurements were taken at 116 ground-based and tall building and tower-based chemical and meteorological measurement sites and a series of six airborne chemical measurement platforms. The most significant feature of the Nashville/Middle Tennessee Ozone Study was a coordinated series of 40+ aircraft studies to measure physical and chemical characteristics of urban and industrial plumes. (Note: an earlier ozone-focused set of field studies was also conducted in the Atlanta, GA area during the summers of 1990 - 1992.)
North Atlantic Regional Experiment (NARE)	NOAA	various sites, 1 ship	1993	O3, NO, NO2, NOx, NOy, VOC, Surface Meteorology	http://www.igac.noaa.gov/newsletter/24/introduction.php	The NARE program measured the type and amount of air pollutants being transported from the North American continent to the Northern Atlantic Ocean. Since the Northeast United States and Nova Scotia, Canada are the last land locations as air masses move out over the ocean, measurements were made a number of land and island sites in Maine, Nova Scotia, and Sable Island. Acadia National Park participated in this study

Footnotes:

1. EPA -- Environmental Protection Agency
   NASA -- National Aeronautics and Space Administration
   NOAA -- National Oceanic and Atmospheric Administration
   NPS -- National Park Service
   NSF -- National Science Foundation
   UCSD -- University of California San Diego (Scripts Institution of Oceanography)

2. This study is part of the Central California Air Quality Studies (CCAQS) which comprise the California Regional Particulate Air Quality Study (CRPAQS) and the Central California Ozone Study (CCOS). CCAQS is a multi-year effort of meteorological and air quality monitoring, emission inventory development, data analysis, and air quality simulation modeling. Prior studies in California included: Southern California Ozone Study (SCOS97) -- 1997; Integrated Monitoring Study (IMS95) -- 1995; San Joaquin Valley Air Quality Study (SJVAQS) -- 1990; SARMAP Ozone Study -- 1990; Southern California Air Quality Study (SCAQS) -- 1987.

3. Historically, there have been many other field studies in the 1960's - 1990's that are not reflected in this table that involve both fixed monitoring sites and aircraft; well known examples include Regional Air Pollution Study (RAPS), Large Power Plant Effluent Study (LAPPES), Northeast Corridor Regional Modeling Program (NECRMP), Northeast Regional Oxidant Study (NEROS), Persistent Elevated Pollutant Episode (PEPE), and Lake Michigan Ozone Study (LMOS).

4. In addition to the air monitoring networks and related studies detailed in this table that are primarily concerned with lower tropospheric air pollution, there are a large number of observations and studies conducted by NASA, NOAA and others that address such topics as (1) upper tropospheric and stratospheric ozone and aerosols, (2) cloud processes, and (3) validation experiments for satellite observations. These studies include but are not limited to:

-- Stratospheric Tropospheric Exchange Project (STEP) – 1987
-- Airborne Antarctic Ozone Experiment (AAOE) – 1987
-- Airborne Arctic Stratospheric Experiment (AASE) – 1989
-- Airborne Arctic Stratospheric Experiment II (AASE2) – 1992
-- Stratospheric Photochemistry Aerosols and Dynamics Experiment (SPADE) – 1993
-- Airborne Southern Hemisphere Ozone Experiment / Measurements for Assessing the Effects of Stratospheric Aircraft (ASHOE/MAESA) – 1994
-- Stratospheric Tracers of Atmospheric Transport (STRAT) – 1995-1996
-- Tropical Ozone Transport Experiment (TOTE) and Vortex Ozone Transport Experiment (VOTE) – 1995-1996
-- Subsonic Aircraft: Contrail and Clouds Effects Special Study (SUCCESS) – 1996
-- Photochemistry and Ozone Loss in the Arctic Region in Summer (POLARIS) – 1997
-- Subsonic Assessment: Ozone and Nitrogen Oxide Experiment (SONEX) – 1997
-- Texas Florida Underflights A (TEFLUN) – 1998
-- The Third Convection and Moisture Experiment (CAMEX 3) – 1998
-- TRMM Brazil Validation Experiment (TRMM-LBA) – 1999
-- TRMM Kwajalein Validation Experiment (KWAJEX) – 1999
-- Nauru 1999 Field Campaign – 1999
-- South African Fire-Atmosphere Research Initiative 2000 (SAFARI) – 2000
-- SAGE III Ozone Loss and Validation Experiment (SOLVE) – 1999-2000
-- ERAST Predator-B RPV Homepage (ERAST) – 2000
-- CAMEX 4 The Fourth Convection and Moisture Experiment (CAMEX 4) – 2001
-- East Pacific Investigation of Climate (EPIC) 2001 Field Program – 2001
-- The Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL FACE) – 2002
-- The SAGE III Ozone Loss and Validation Experiment (SOLVE II) – 2003
-- The Aura Validation Experiment (AVE) – 2004
-- The Intercontinental Chemical Transport Experiment – North America (INTEX-NA) – 2004
-- The Aura Validation Experiment Houston (AVE Houston) – 2004
-- North American Monsoon Experiment (NAME) – 2004
-- Winter Storms Reconnaissance Program 2004 (WSR2004) – 2004
-- Polar Aura Validation Experiment (PAVE) – 2005
-- The Tropical Cloud Systems and Processes Mission (TCSP) – 2005
-- UAS Flight Demonstration Project 2005 – 2005

TABLE 3.
AIR MONITORING NETWORKS FOR CLIMATE FORCING, TRANSPORT, AND STRATOSPHERIC OZONE

Network	Lead Federal Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Global Monitoring Division Baseline Observatories					
Mauna Loa	NOAA	1	1957	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/MLO/
Point Barrow	NOAA	1	1973	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/BRW/
Samoa	NOAA	1	1974	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/smo/
South Pole	NOAA	1	1957	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/SPO/
Trinidad Head	NOAA	1	2002	CO2, CO, CH4, SO2, O3, SF6, N2O, H2, CFCs, HCFCs, HFC's, Aerosols, Solar Radiation, Surface Meteorology	http://www.cmdl.noaa.gov/obop/THD/
Global Monitoring Division -- Carbon Cycle Greenhouse Gases Group (CCGG)					
Observatory Measurements	NOAA	4	1957	See above baseline observatories	http://www.cmdl.noaa.gov/ccgg/insitu.html
Cooperative fixed sites	NOAA	62	1967	CO2, CH4, CO, H2, N2O, and SF6, stable isotopes of CO2 and CH4	http://www.cmdl.noaa.gov/ccgg/flask.html
Commercial Ships	?????	?????	?????		
Others					
ALE / GAGE / AGAGE Network	NASA	5 Current 2 Discontinued	1978	CO, CH4, SF6, N2O, H2, CFCs, HCFCs, HFC's, methyl chloroform, carbon tetrachloride, chloroform, perchloroethylene, halons & others	http://cdiac.ornl.gov/ndps/alegage.html
Tall Tower Measurements	NOAA	3	1992	CO2, CO, CH4, H2, CFCs, methyl chloroform, carbon tetrachloride, chloroform, sulfur hexafluoride, perchloroethylene	http://www.cmdl.noaa.gov/ccgg/towers.html
Aircraft Measurements	NOAA	16 airport sites	1992	CO2, CH4, N2O, CO, H2, SF6	http://www.cmdl.noaa.gov/ccgg/aircraft.html
Networks for Halogenated Gases and Ozone	NOAA	Multiple platforms	1986	nitrous oxide (N2O), CFCs, HCFCs, HFCs, CH3Br, CH3Cl, CH3I), halons	http://www.cmdl.noaa.gov/hats/
Network for Aerosols	NOAA	Multiple platforms	mid-1970s	light absorption, total scattering and backscattering	http://www.cmdl.noaa.gov/aero/
North American Aircraft and Tall Tower Carbon Observing System	NOAA	10 Aircraft 3 tall towers	1992	CO, CO2, CH4	http://www.cmdl.noaa.gov/carbonamerica/
North American Carbon Program Atmospheric Observing System	Multiple participants	Multiple platforms	2001	CO, CO2, CH4	http://www.nacarbon.org/nacp/
AERONET -- AErosol RObotic NETwork	NASA	22+ other participants	1998	Aerosol spectral optical depths, aerosol size distributions, and precipitable water	http://aeronet.gsfc.nasa.gov/index.html

TABLE 3.
AIR MONITORING NETWORKS FOR CLIMATE FORCING, TRANSPORT, AND STRATOSPHERIC OZONE
(continued)

University of Washington					
Cheeka Peak Observatory	None	1	1997	O3, CO, Aerosols, Solar Radiation, Surface Meteorology	http://research.uwb.edu/jaffegroup/modules/cpo_plot/
Mt. Bachelor Observatory	None	1	2004	O3, CO, NO/NO2, Aerosols, Hg, Surface Meteorology	http://research.uwb.edu/jaffegroup/modules/mbo_plot/
International Aircraft Measurements					
MOZAIC (Measurement of ozone, water vapour, carbon monoxide and nitrogen oxides aboard Airbus in-service aircraft)	None	2500 Airbus international flights/year	1994	O3, H2O, CO, NOx	http://www.fz-juelich.de/icg/icg-ii/mozaic/home
NOXAR (Measurements of Nitrogen Oxides and Ozone Along Air Routes)	None	500 Swiss Air flights to U.S. and far east	1995 - 1996	O3, NO, NO2	http://www.iac.ethz.ch/en/research/chemie/tpeter/Noxar.html
CARIBIC (Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container)	None	~100 Lufthansa flights	1997	CO, O3, CO, CH4, CO2, N2O, SF6, NMHC, Position & Meteorology and Cloud cover.	http://www.caribic-atmospheric.com/
AMATRAS (Atmospheric Measurement by Airliners for Trace Species)	None	262 flights between Japan and Australia	1993	CO2, CH4, CO and SF6	http://www.jal.com/en/press/0000336/img/AMATRAS.pdf

TABLE 4. OBSERVATION SYSTEMS PROVIDING VERTICAL PROFILE INFORMATION

Network	Lead Federal Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Routine Observations from Towers, Lidar, Sondes, Aircraft					
Tall Tower Measurements	NOAA	3	1992	CO2, CO, CH4, H2, CFCs, methyl chloroform, carbon tetrachloride, chloroform, sulfur hexafluoride, perchloroethylene	http://www.cmdl.noaa.gov/ccgg/towers.html
Research Wind Profiler Network	NOAA	variable	???	Vertical wind and temperature profiles, surface meteorology	http://www.etl.noaa.gov/et7/data/
REALM – Regional East Atmospheric Lidar Mesonet	NOAA	13	2004	Lidar measurements for mixing height and vertical profiling of aerosols, ozone and water vapor	http://alg.umbc.edu/REALM/
Ozonesonde Network	NOAA	4 (8?)	???	Weekly Upper Air measurements of ozone, temperature, and humidity information from surface to approximately 32 km	http://www.cmdl.noaa.gov/ozwv/ozsondes/
SHADOZ Network (Southern Hemisphere ADditional Ozonesondes)	NASA	14	1998	Upper air measurements of ozone, temperature, and humidity	http://croc.gsfc.nasa.gov/shadoz/
In-situ Aerosol Profiling Aircraft	NOAA	1	2000	Vertical profiles of aerosol properties including light scattering and absorption to 3.7 km asl. Other measurements of CO2, CH4, N2O, CO, H2, SF6	http://www.cmdl.noaa.gov/ccgg/aircraft.html
AERONET -- AErosol RObotic NETwork	NASA co-located networks	22 + other participants	1998	Aerosol spectral optical depths, aerosol size distributions, and precipitable water	http://aeronet.gsfc.nasa.gov/index.html
MPLNET – Micro-pulse Lidar Network		8	2000	Aerosols and cloud layer heights	http://mplnet.gsfc.nasa.gov/
Routine International Aircraft Measurements					
MOZAIC (Measurement of ozone, water vapour, carbon monoxide and nitrogen oxides aboard Airbus in-service aircraft)	None	2500 Airbus international flights/year	1994	O3, H2O, CO, NOx	http://www.fz-juelich.de/icg/icg-ii/mozaic/home
NOXAR (Measurements of Nitrogen Oxides and Ozone Along Air Routes)	None	500 Swiss Air flights to U.S. and far east	1995 - 1996	O3, NO, NO2	http://www.iac.ethz.ch/en/research/chemie/tpeter/Noxar.html
CARIBIC (Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container)	None	~100 Lufthansa flights	1997	CO, O3,CO, CH4, CO2, N2O, SF6, NMHC, Position & Meteorology and Cloud cover.	http://www.caribic-atmospheric.com/
AMATRAS (Atmospheric Measurement by Airliners for Trace Species)	None	262 flights between Japan and Australia	1993	CO2, CH4, CO and SF6	http://www.jal.com/en/press/0000336/img/AMATRAS.pdf
NOAA Research Observing Systems (Systems typically incorporated in intensive field campaigns)					
Lockheed WP-3D Orion	NOAA	1 aircraft	???	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters, altitude	http://esrl.noaa.gov/csd/2006/p3science.html
R/V Ronald H. Brown	NOAA	1 ship	???	O3, NO, NO2, NOy, VOCs, CO2, CO, SO2, HNO3, NH3, other reactive pollutants, aerosols, meteorological parameters & upper air	http://esrl.noaa.gov/csd/2006/rhbscience.html
Remote Sensing Aircraft	NOAA	1 aircraft	???	Remote sensing (lidar) of O3, aerosols and meteorological parameters	http://esrl.noaa.gov/csd/2006/toscience.html
Twin Otter	NOAA	1 aircraft	???	O3, CO, CO2, SO2, NO, NOx, NOy, reactive pollutants, major ions, aerosol size	http://esrl.noaa.gov/csd/2006/toscience.html

TABLE 5. NATIONAL ROUTINE METEOROLOGICAL MONITORING NETWORKS

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
ASOS -- Automated Surface Observing System	NOAA	~1000 (supplemented by military weather observation sites)	1992 (replaced routine surface observations collected manually at 260 Weather Service facilities)	Continuous measurements of: Wind Direction and Wind Speed; Visibility; Runway Visual Range; Type, intensity and amount of rain, snow, etc.; Obstructions due to fog, mist, etc.; Cloud Height and Amount; Ambient Temperature; Dew Point Temperature; Pressure; Lightning detection; Automated, manual, and plain language remarks on special weather conditions (depending on level of service); and Additive and automated maintenance data on precipitation amount, max/min temperature, pressure tendency, etc.	http://www.nws.noaa.gov/asos/pdfs/aum-toc.pdf
Cooperative Observer Program	NOAA	~11,400	1890	24-hour maximum and minimum temperatures, Liquid equivalent of precipitation, snowfall, snow depth, and Other special phenomena such as days with thunder, hail, etc.	http://www.nws.noaa.gov/om/coop/coopmod.htm
SLAMS – State and Local Ambient Monitoring Stations	EPA	~3000	1978	Wind direction and speed, Temperature, Precipitation, Relative humidity	http://www.epa.gov/ttn/airs/airsaqs/aqsweb/aqswebhome.htm
Remote Automated Weather Stations	DOA	~2200	~1978	Wind direction and speed, Precipitation, Pressure, Temperature, Relative humidity, Fuel moisture and temperature	http://www.fs.fed.us/raws/raws101.shtml
NOAA Profiler Network (and Cooperative Agency Profilers)	NOAA	35 (plus ~100 CAP sites)	1992	Vertical profiles of wind direction and speed (and vertical profiles of temperature at RASS sites)	http://www.profiler.noaa.gov/npn/
Upper Air Stations (Weather Balloons)	NOAA	102 in North America, Pacific Islands, and the Caribbean	1937	Measurements of temperature, relative humidity, wind direction and speed, and altitude/height at selected pressure levels.	http://www.ua.nws.noaa.gov/net-info.htm
Forecast Systems Laboratory Aircraft Communications Addressing and Reporting System	NOAA	~4000 commercial aircraft	2001 (routinely available database)	Wind direction, wind speed and temperature reported for various altitudes at which aircraft typically operate	http://acweb.fsl.noaa.gov/FAQ.html#variables
National Doppler Radar Sites	NOAA	158	1990 (national radar network originated prior to 1960)	Base Reflectivity, Composite Reflectivity, One-Hour Precipitation, and Storm Total Precipitation	http://www.srh.noaa.gov/radar/radinfo/radinfo.html
National Lightning Detection Network	Commercial	100+	1989	Detection of cloud-to-ground lightning flashes at distances up to 400 km	http://www.nwstc.noaa.gov/METEOR/Lightning/detection.htm
National Environmental Satellite, Data, and Information Service	NOAA	2 GOES satellites 2 POES satellites	1994 (earlier satellite systems replaced)	Vertical profiles of temperature, moisture, and wind; visible and infrared imagery of clouds; water vapor imagery	http://www.goes.noaa.gov/
C-MAN – Buoy and Coastal-Marine Observing Network	NOAA	70	Early 1980s	Pressure, wind direction, wind speed and gust, and air temperature, relative humidity, precipitation, visibility, sea water temperature, water level, and waves	http://www.ndbc.noaa.gov/cman.php

TABLE 6. SATELLITE – BASED AIR QUALITY OBSERVING SYSTEMS[1,4]

Instrument	Satellite Platform[3]	Lead Federal Agency	Initiated	Measurement Parameters	Orbit & Horizontal Resolution	Location of Information and/or Data
OLS (Operational Linescan System)	DMSP satellites	DOD	1962?	Identify fires and smoke plumes	Polar Imagery only	http://www.af.mil/factsheets/factsheet.asp?fsID=94
BUV (Backscatter Ultraviolet Spectrometer)	Nimbus 4	NASA	1970-1980	O3, CO2, SO2	Sun synchronous	http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=1970-025A
SBUV (Solar Backscatter Ultraviolet Spectrometer)	Nimbus 7	NASA	1978-1993	O3, SO2	Polar	http://jwocky.gsfc.nasa.gov/n7toms/nimbus7tech.html
TOMS (Total Ozone Mapping Spectrometer)	Nimbus 7 Meteor 3 Earth-Probe	NASA	1978-1993 1991-1994 1996	O3, SO2, Aerosols	Polar ~100km	http://toms.gsfc.nasa.gov/fltmodel/spacecr.html
LIMS (Limb Infrared Monitor of the Stratosphere	Nimbus 7	NASA	1978-1979	O3, HNO3, NO2,	Polar	http://lims.gats-inc.com/about_lims.html
ATMOS (Atmospheric Trace Molecule Spectroscopy)	Spacelab 3 ATLAS -- 1,2,3	NASA	1985, 1992, 1993, 1994	O3, CFCl3, CF2Cl2, ClONO2, HCl, HF, CO, CH4, HCN, HNO3, NO, NO2, N2O, N2O5, Aerosols		http://remus.jpl.nasa.gov/atmos/sl3.html
CLAES (Cryogenic Limb Array Etalon Spectrometer)	UARS	NASA	1991-1993	O3, CFCl3, CF2Cl2 ClONO2, CH4, HNO3, NO, NO2, N2O, N2O5, Aerosols		http://umpgal.gsfc.nasa.gov/
HALOE (Halogen Occultation Experiment)	UARS	NASA	1991-2005	O3, HCl, HF, CH4, NO, NO2, Aerosols		http://umpgal.gsfc.nasa.gov/
ISAMS (Improved Stratospheric and Mesospheric Sounder)	UARS	NASA	1991-1992	O3, CO, CH4, NO2, N2O, N2O5, Aerosols		http://umpgal.gsfc.nasa.gov/
MLS (Microwave Limb Sounder)	UARS	NASA	1991-1999	O3, ClO, CH3CN, HNO3, SO2		http://umpgal.gsfc.nasa.gov/
GOES Imager (Geostationary Operational Environmental Satellites)	GOES-10 GOES-12	NOAA	1994	Fire products for WF_ABBA (imagery) and GASP (aerosol optical depth)	Geostationary	http://www.nesdis.noaa.gov/
GOES Sounder (Geostationary Operational Environmental Satellites)	GOES-10 GOES-12	NOAA	1994	Total column O3	Geostationary	http://cimss.ssec.wisc.edu/goes/goesmain.html#sndrinfo
AVHRR (Advanced Very High Resolution Radiometer)	NOAA-15 NOAA-16 NOAA-17[2]	NOAA	1998	Aerosol optical depth, particle size information and vegetation/drought index products related to air quality through fires	Polar 4km	http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html
SBUV/2 (Solar Backscattered Ultraviolet Radiometer Model 2)	NOAA-16 NOAA-17[2]	NOAA	2000	Total and profile O3 from surface to top of atmosphere in ~5 km thick Umkehr layers	Polar	http://www2.ncdc.noaa.gov/docs/podug/html/c4/sec4-4.htm

TABLE 6. SATELLITE – BASED AIR QUALITY OBSERVING SYSTEMS[1,4] (continued)

MOPITT (Measurement of Pollution in the Troposphere)	EOS Terra	NASA	1999	CO, CH4	Polar 22 x 22 km^2	http://www.eos.ucar.edu/mopitt/
MISR (Multi-angle Imaging SpectroRadiomenter)	EOS Terra	NASA	1999	Aerosol properties and plume height information near the vicinity of fires	Polar ~1km	http://www-misr.jpl.nasa.gov/mission/introduction/welcome.html
MODIS (Moderate Resolution Imaging Spectroradiometer)	EOS Terra EOS Aqua	NASA	1999 2002	O3, Aerosol optical depth, particle size information, fine particle fraction, and forest fires	Polar 1km	http://modarch.gsfc.nasa.gov/index.php
AIRS (Atmospheric Infrared Sounder)	EOS Aqua	NASA	2002	Total column ozone, surface temperature, temperature and moisture vertical profiles, (plus under development are CO and CO2 total column, O3 vertical distribution, and CH4 distribution)	Polar 50km	http://www-airs.jpl.nasa.gov/
HIRDLS (High Resolution Dynamics Limb Sounder)	EOS Aura	NASA	2004	O3, CFCl3, CF2Cl2, ClONO2, CH4, HNO3, NO2, N2O, N2O5, Aerosols	Polar	http://aura.gsfc.nasa.gov/index.html
MLS (Microwave Limb Sounder)	EOS Aura	NASA	2004	O3, BrO, ClO, HOCl, HCl, CO, HCN, CH3CN, HNO3, N2O, OH, HO2, SO2	Polar	http://aura.gsfc.nasa.gov/index.html
OMI (Ozone Monitoring Instrument)	EOS Aura	NASA	2004	O3, BrO, OClO, HCHO, NO2, SO2 and aerosol	Polar 12 x 24 km^2	http://aura.gsfc.nasa.gov/index.html
TES (Total Emission Spectrometer)	EOS Aura	NASA	2004	O3, NOy, CO, SO2, CH4	Polar 26 x 42 km^2	http://aura.gsfc.nasa.gov/index.html
CALIPSO (Cloud-Aerosol Lidar & Infrared Pathfinder Satellite Observations)	CALIPSO	NASA	2005	Aerosol optical depth, backscatter, extinction	Polar 0.3 x 0.3 km^2	http://www-calipso.larc.nasa.gov/about/
OMPS (Ozone Mapping and Profiling Suite)	NPOESS - Preparatory Project	NOAA	2006	Total column and vertical profile ozone data	Polar	http://www.ipo.noaa.gov/Projects/npp.html
VIIRS (Visible Infrared Imaging Radiometer Suite)	NPOESS - Preparatory Project	NOAA	2006	Aerosol optical depth	Polar	http://www.ipo.noaa.gov/Projects/npp.html
Orbiting Carbon Observatory	OCO	NASA	2008	CO2	Polar	http://oco.jpl.nasa.gov/
APS & TIM (Aerosol Polarimetry Sensor & Total Irradiance Monitor)	Glory	NASA	2008	Black carbon soot, other aerosols, total solar irradiance, cloud images	Sun-synchronous, circular, Low Earth Orbit	http://glory.gsfc.nasa.gov/

Footnotes:

1. Non-U.S. satellite systems are not included in table at this time.

2. As of 3/15/06 the operational satellite platforms may need to include NOAA-18.

3. CALIPSO -- Cloud-Aerosol Lidar & Infrared Pathfinder Satellite Observations
   DMSP -- Defense Meteorological Satellite Program
   EOS -- Earth Observing System
   GOES -- Geostationary Operational Environmental Satellites
   NOAA -- National Oceanic and Atmospheric Administration
   NPOESS -- National Polar-orbiting Operational Environmental Satellite System
   OCO -- Orbiting Carbon Observatory
   UARS -- Upper Atmosphere Research Satellite

4. See the following table for additional information on NASA satellites, instrument systems, pollutants measured, and data availability:

Key Atmospheric Chemistry & Dynamics Data Sets at the NASA Goddard DAAC

Missions	Nimbus 4	Nimbus 7	Nimbus 7 Meteor 3 ADEOS 1 Earth-Probe	Nimbus 7	Spacelab 3, ATLAS 1,2,3	UARS				ERS-2	Terra Aqua	Aqua	Aura			
Instruments	**BUV**	**SBUV**	**TOMS**	**LIMS**	**ATMOS**	**CLAES**	**HALOE**	**ISAMS**	**MLS**	**GOME**	**MODIS**	**AIRS**	**OMI**	**HIRDLS**	**MLS**	**TES***
Data Period	Apr '70-May '77	Nov '78-May '93	Nov '78-Present	Oct '78-May '79	'85, '92, '93, '94	Oct '91-May '93	Oct '91-Present	Sep '91-Jul '92	Sep '91-Jul '99	April '95-Present	Mar '00-Present	Sep'02-Present	Jul'04-Present	Jul'04-Present	Jul'04-Present	Jul'04-Present
Spectral Region	255 - 380 nm	255 - 340 nm	309 - 360 312 - 380 nm	6.2 - 15 μm	2.98 - 15 μm	3.5 -12.7 μm	2.43 -10.25 μm	4.6 -16.6 μm	63, 183, 205 GHz	240 - 790 nm	0.4 -14 μm	0.4 -1.1, 3.74 -15.4 μm	270 - 500 nm	6.12 -17.76 μm	118, 190, 240, 640 GHz, 2.5 THz	3.2 -15.4 μm
Bands	13	13	6	6	16	9	8	8	3	3072	36	2382	1560	22	5	12
O_3	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
BrO										•			•		•	
$CFCl_3$					•	•								•		
CF_2Cl_2					•	•								•		
ClO									•						•	
OClO										•			•			
$ClONO_2$					•	•								•		
HOCl															•	
HCl					•		•								•	
HF					•		•									
HCHO										•			•			
CO					•			•				•			•	•
CH_4					•	•	•	•				•		•		•
CH_3CN									•							
HCN					•										•	
HNO_3				•	•	•			•					•	•	•
NO					•	•	•									
NO_2				•	•	•	•	•		•			•	•		•
N_2O					•	•		•						•	•	
N_2O_5					•	•		•						•		
OH															•	
HO_2															•	
H_2O / Humidity				•	•	•	•	•	•	•	•	•		•	•	•
SO_2	•	•	•						•	•			•		•	
Aerosols			•		•	•	•	•			•		•	•		
Cloud	•	•	•								•	•	•	•		
Temperature				•		•	•	•	•		•	•		•	•	•
Geopotential Height				•					•			•		•	•	
Reflectance	•	•	•								•	•	•			

Please note that the table above does not contain parameters from all sensors and products. Also available from the GES DAAC are many more Atmospheric and Earth Sciences data products from AIRS, AMSU-A, HSB, MODIS, SeaWiFS, OCTS, CZCS, TRMM (PR, TMI, VIRS), TOVS Pathfinder, Data Assimilation Model (GEOS-1, GEOS-DAS, CPC/ACDB), UARS (HRDI, WINDII, SOLSTICE, SUSIM, PEM), SORCE, several Field Campaigns, and Interdisciplinary data sets consisting of 70 geophysical Earth Sciences parameters. TOMS & SBUV reprocessed data (version-8) are now available on DVD-ROM. The MLS and OMI-Aura products & Visualization tools are now available from GES DISC.

* Data from the Aura instrument 'TES' is archived at the NASA Langley Atmospheric Sciences Data Center (http://eosweb.larc.nasa.gov/).

http://disc.gsfc.nasa.gov/ help@disc.gsfc.nasa.gov

TABLE 7. EUROPEAN AIR MONITORING NETWORKS

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
EMEP -- Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (encompasses networks for ~37 European countries and organizations)	UNECE	270	1977	**Acidifying / Eutrophying Compounds** (precipitation): SO4, NO3, NH4, trace elements, pH, acidity (air): SO2, NO2, HNO3, NH3, PM10, PM2.5, major ions **O3** **Heavy Metals** precipitation, major ions, PM2.5, PM10, Hg, wet deposition **POPs** precipitation, air, deposition **Particulate Matter** PM2.5, PM10, EC, OC, TC, BC **VOC** Hydrocarbons, Carbonyls	http://www.nilu.no/projects/ccc/emepdata.html
EUROTRAC -- The European Experiment on the Transport and Transformation of Environmentally Relevant Trace Constituents over Europe	International Executive Committee (European Countries)	???	1986	EUROTRAC programs performed analyses utilizing data from existing or specially designed monitoring networks in order to: 1. elucidate the chemistry and transport of ozone and other photo-oxidants in the troposphere, e.g., TOR -- 30 O3 stations and ALPTRAC -- 15 snow monitoring sites 2. identify processes leading to the formation of acidity in the atmosphere, particularly those involving aerosols and clouds. 3. understand uptake and release of atmospheric trace substances by the biosphere.	http://www.gsf.de/eurotrac/index_what_is.html
EUROTRAC-2 -- The EUREKA project on the transport and chemical transformation of trace constituents in the troposphere over Europe; second phase. Subprojects: – AEROSOL – BIATEX-2 – CAPMAN – CMD – EXPORT-E2 – GENEMIS – GLOREAM – LOOP – MEPOP – PROCLOUD – SATURN – TOR-2 – TRAP45 – TROPOSAT	International Scientific Secretariat (European Countries and EU)	???	1996	EUROTRAC-2 programs performed analyses utilizing data from existing monitoring networks in order to: support the further development of abatement strategies within Europe by providing an improved scientific basis for the quantification of source-receptor relationships for photo-oxidants and acidifying substances.	http://www.gsf.de/eurotrac/index_what_is.html

TABLE 8. MONITORING NETWORKS FOR PERSISTENT ORGANIC POLLUTANTS (POPs)

Network	Lead Agency	Number of Sites	Initiated	Measurement Parameters	Location of Information and/or Data
Global Monitoring of Persistent Organic Pollutants (POPs)[1]	UNEP – United Nations Environment Programme	N/A	2003	Activities include developing guidance on sampling and analysis of POPs, QA/QC procedures, data treatment and communication and data assessment. In addition the programme will include an electronic discussion group on POPs monitoring issues where existing programs and laboratories are invited to participate and share their experience on this subject.	http://www.chem.unep.ch/gmn/default.htm
AMAP – Artic Monitroing and Assessment Programme	NOAA (as U.S. representative to the 8 nation Artic Council)	???	~1991	Air/aerosol sampling for POPs, heavy metals, radioactivity and acidification parameters; bulk precipitation and snowpack sampling to estimate deposition[2]	http://www.amap.no/
EMEP -- Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe	UNECE – United Nations Economic Commission for Europe	17	1991	Benzo(a)pyrene, PCBs, hexachlorobenzene, Chlordane, lindane, hexachlorocyclohexane, DDT/DDE in precipitation and gas particles	http://www.chem.unep.ch/gmn/012_emep.htm
GAPS – Global Atmospheric Passive Sampling	UNEP – United Nations Envrionment Programme	50	2004	12 chemicals including Aldrin, Chlordane, DDT, Deldrin, Endrin, Heptachlor, Hexachlorobenzene, Mirex, PCBs, Dioxins(PCDDs), Furans(PCDFs), Toxaphene and other pollutants	http://pubs.acs.org/cgi-bin/article.cgi/esthag/2004/38/i17/html/es040302r.html
NDAMN – National Dioxin Air Monitoring Network	EPA	34	1998 - 2005	CDDs. CDFs, dioxin-like PCBs	http://cfpub2.epa.gov/ncea/cfm/recordisplay.cfm?deid=22423
IADN -- Integrated Atmospheric Deposition Network	EPA	20	1990	PAHs, PCBs, and organochlorine compounds are measured in air and precipitation samples	http://www.epa.gov/glnpo/monitoring/air/
EMAP – Environmental Monitoring and Assessment Program	EPA	12,600	1988	Oriented to ecological and water monitoring	http://www.epa.gov/emap/index.html

Footnotes:

1. The 12 POPs targeted by the United Nations sponsored Stockholm Convention (December 2000) are Aldrin, Chlordane, Dieldrin, DDT, Endrin, Heptachlor, Mirex, Toxaphene, Polychlorinated Biphenyls (PCBs), Hexachlorobenzene (HCB), Dioxins, and Furans.

2. For AMAP the following pollutants are monitored:

-- POPs include such pollutant families as Chlorobenzenes, Hexachlorocyclohexanes, Clordanes, Heptachlor, DDT, Mirex, Toxaphene, Dieldrin/endrin, PCDD/PCDF, Non-ortho PCBs (coplanars), PCB congeners, Current use pesticides, Polycholrinated naphthalenes, Short chain chlorinated paraffins (CP), other POPs, PAHs and petroleum hydrocarbons.

-- Heavy metals include Cd, Cu, Hg, Pb, Zn, Cr, Ni, As, Se, Al, Fe, and V.

-- Radiactivity includes Gamma spectroscopy, ^{131}I, ^{137}Cs, ^{134}Cs, ^{90}Sr, ^{210}Po, ^{99}Tc, and $^{239,240}PU$.

-- Acidification parameters include SO2, NOx, NH3, pH, SO4, NO3, NH4, DOC, Mg, Ca, K, Na, AL, Cl, Conductivity, N_{tot}, P_{tot}, and Particulates.